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MANUFACTURING METHODS AND TECHNOLOGY FOR MICROWAVE STRIPLINE CIRCUITS

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This is the final report for work performed on the MANTECH Microwave Stripline Circuit program for the period from 15 January 1981 to 26 February 1982.
An investigation was made of the effect of tolerances on a broadband, three-layer, stripline circuit. Tolerances on the following parameters were considered the dielectric constant of the stripline material, thicknesses of the materials, circuit line widths, alignment of circuits and the surface roughness of the copper cladding. The investigation used both analyses and measurements of actual

20. ABSTRACT (Continued)

stripline circuits. An investigation was also made of methods of measuring dielectric constant of the stripline material.

The results of the study indicate that a printed wiring board facility can fabricate microwave stripline components if there is good control of all processes. This requires precision measurements of resist photospeed to compensate for lot variations, a highly uniform intensity output of exposure units and also feed and bleed chemical add systems to maintain bath chemistry. Alignment of phototools and machining of the circuit boards is compatible with the CAD/CAM facility and numerically controlled machine tools.

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SECTION I

FOREWORD

This is the final report for the work performed on Contract DAAH01-81-D-A002, Task 0005, RF Stripline Task for the period from 15 January 1981 to 26 February 1982.

SECTION II
INTRODUCTION AND SUMMARY

The systems requirements for military hardware have generated the need for custom microwave strip transmission line devices. To reduce the manufacturing costs and enhance the producibility of these devices, it is necessary to generate a generic production system of strip transmission line manufacturing equipment that emphasizes automated processes and fabrication as much as possible.

To achieve this goal, the following tasks were undertaken and are described in this report:

1) An investigation was made of the sensitivity of strip transmission line tolerances to establish maximum acceptable values in a production environment.

2) An investigation was made of methods of measuring the dielectric constant of stripline substrate materials that would be suitable for production lot testing. The RF performance of candidate substrate materials was also evaluated.

3) Methods were established for machining, photolithography and registration.

4) A method was developed for precision lamination of multilayered stripline circuits.

5) Production techniques were developed for plated-through holes in stripline substrate materials and for shell plating of laminated assemblies.

The Hughes-Tucson Process Engineering Printed Wiring Board Department participated in the study in cooperation with Hughes Canoga Park Radar Laboratory to determine if RF stripline fabrication processes are interchangeable with present state-of-the-art printed wiring board fabrication techniques.

The equipment available for this study represents a quality printed wiring board facility capable of producing high volume polyimide multilayers to Military Standards (MIL-P-55110).

Included in this equipment is a CAD/CAM computer facility for making digitized machining tapes, a CNC drill machine, a CNC route machine, automated plating lines for electroless copper and electrolytic copper deposition, a Riston PC-24 printer (Riston is a trademark of E. I. DuPont), an associated laminator, a resist processor and stripper, a DEA 24-inch conveyorized alkaline etch and clean system and a Pasadena Hydraulics, Inc., electric lamination press capable of laminating high temperature substrates. A complete listing of all equipment used is given in Appendix A.

The results of this study indicate that the printed wiring board facility can fabricate RF stripline components if the shop is capable of precision control of all its processes. This requires sophisticated chemical analysis system, feed and bleed chemical add systems to maintain steady state bath chemistry, a highly uniform intensity output on the exposure units for imaging resist and precision measurements of photospeed to compensate for lot variation in resist. In addition, the application of plating often requires special fixturing and anode placement for through hole and shell plating which are not routine in most printed wiring board facilities.

The investigation of stripline tolerances and substrate materials used both analysis and measurements of actual stripline circuits. The analysis of tolerances and the physics of rough surfaces played a key role in this investigation. It would not have been possible to relate the differences in measured performance to the many different parameters without the insight provided by the analysis.

SECTION III
STRIPLINE CIRCUIT SELECTION

Stripline is a very broad general term, usually referring to either a two-layer or three-layer construction, as shown in Figure 1, where inner conductors are immersed in a common dielectric medium and the structure is shielded by a continuous outer conductor. There are also variations of construction, such as air dielectric stripline and microstrip, where the dielectric medium is not uniform. These are shown in cross section in Figure 2. The particular type of stripline to be used is chosen for a variety of reasons but most important is usually 1) the type of circuits required, such as couplers, filters, power dividers, etc., and 2) the frequency bandwidth over which the circuits must operate.

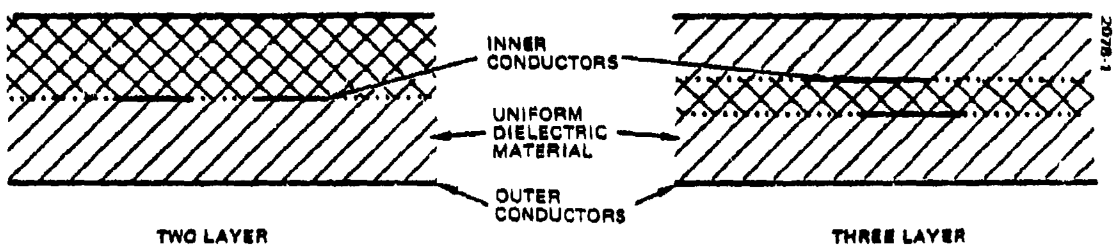


Figure 1. Stripline Construction Common Types

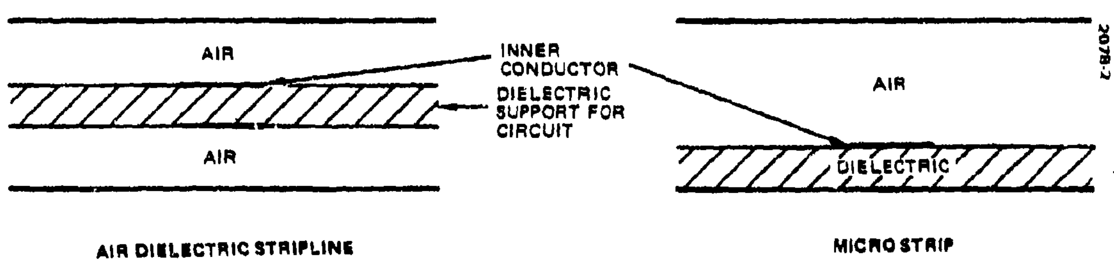


Figure 2. Stripline Construction Variations

The design and fabrication requirements of the various types of stripline were carefully reviewed. Certain types of stripline circuits are quite easy to produce and do not have many critical parameters. Other types of circuits have proven to be difficult to produce consistently with the required performance tolerances. These usually involve three-layer construction, broad frequency bandwidths and tight amplitude and phase tracking requirements between the outputs.

Therefore, the efforts of this program have been focused on the boardband, three-layer stripline circuit. The following rationale was used to support the concentration on the three-layer stripline coupler:

- 3 dB hybrids are basic circuits for broadband sum and difference circuits and mode formers used in missile guidance.
- There is insufficient coupling in the two-layer configuration to fabricate broadband 3 dB hybrids.
- These circuits have stringent performance requirements and have proven to be difficult to manufacture.
- Fabrication and processing data obtained from three-layer configuration are also applicable to two-layer and other configurations.

The circuit selected for the study is the 3 dB, tandem, quadrature coupler that operates over the frequency range of 2 to 18 GHz. This circuit has been developed for another program and high quality artwork was created from which photo masks could be made.

SECTION IV
STRIPLINE MATERIALS SELECTION

INTRODUCTION

Many types of excellent stripline materials are now available. The majority of these materials are designed for the lower microwave frequency applications where requirements are less critical and the production volume is large. Some materials are also designed primarily for commerical applications and do not meet the environmental requirements for military applications.

The emphasis for this study is on stripline materials suitable for use in broadband stripline coupler type circuits that operate into the J-band frequency region up to 18 GHz. The dielectric material would have low dissipation loss, a relatively low dielectric constant and, especially, uniformity of material properties across each sheet and from sheet to sheet of material.

The stripline circuits that are of concern are for military applications. The stripline materials used for these circuits should, therefore, either meet the requirements of the appropriate military specifications, or at least not be incompatible with the general requirements of the specifications. The materials must also be compatible with the processes, that is imaging, etching, bonding, plating, etc., that are required to fabricate the stripline circuits.

MIL-P-13949F

MIL-P-13949F, General Specification for Plastic Sheet, Laminated, Metal Clad (for Printed Wiring Boards) is the military specification that covers materials for stripline circuits. Revision F of the specification was released on 10 March 1981. This Specification lists three classifications of materials for microwave applications and requires testing at 10 GHz:

- GR - Glass (nonwoven-fiber) base, polytetrafluorethylene resin, flame resistant, for microwave application. (MIL-P-13949/7c)

- GX - Glass (woven-fabric) base, polytetrafluoroethylene resin, flame resistant, for microwave application. (MIL-P-13949/9B)
- GY - Glass (woven-fabric) base, polytetrafluoroethylene resin, flame resistant for microwave application. (MIL-P-13949/14)

All of these materials are polytetrafluoroethlylene (PTFE) based with glass added to stabilize the mechanical properties of the materials. Not included are dielectric materials such as polyolefin and polystyrene, which have excellent electrical characteristics but have poor mechanical properties and a limited temperature range.

The Qualified Products List, QPL-13949-49 dated 12 June 1981 lists the following materials:

- GR(MIL-P-13949/7c)

Oak 700	Oak Materials Group, Inc,
RT/Duroid 5870	Rogers Corp.
RT/Duroid 5880	Rogers Corp.

- GX(MIL-P-13949/9B)

DiClad 527	Keene Corp.
Cu Clad 250 GX	Minnesota Mining and Manufacturing Corp.
OAK602	Oak Materials Group Inc.

- GY(MIL-P-13949/14)

  No Listing

An examination of the military specifications for these materials showed that the tolerance for the dielectric constant was ± 0.04. A tolerance of ± 0.02 is considered a necessity for broadband applications by most users. It was assumed that the tighter dielectric constant would also be necessary to obtain good performance for the circuits tested on this program. The tests, discussed later in this report, showed that the 3 dB quadrature coupler test circuit was, in fact, quite insensitive to differences in dielectric constant. The primary materials that were initially considered for this study were, therefore, limited to a subclass of materials that are made to the requirements of MIL-P-13949F but have the tighter tolerance on dielectric constant.

The experience in the first half of 1981 was that only two materials of suitable quality in the desired range of thickness were available: CuClad 217 made by 3M Corporation and RT/Duroid 5880 made by Rogers Corporation. Both materials exceed the requirements of MIL-P-13949F. Pertinent data are given in Table 1. Unfortunately, the materials have different dielectric constants and thus slightly different circuit designs are required for each material. Thus, assuming tight dielectric tolerances are required for broadband coupled circuit designs, it is not possible to use them interchangeably. The circuit must be designed for the specific material used.

Oak Materials Group and Keene Corporation now make materials that are similar to RT/Duroid 5880 and Cu Clad 217. The material was not available in the desired thickness and tolerance at the start of the program and was not included in the tests. Material was, however, purchased and examined. From visual examination of the Oak 700 material, it appears that the non-woven mixture of PTFE and glass is uniform with only small variations of color across the surface. The Keene Corporation material, Di Clad 880, was also not available in the thickness and tolerances required. Di Clad 880 has a woven glass and a dielectric constant of 2.20. Material that was purchased and examined appeared to have a very uniform, fine weave glass cloth.

TABLE 1. STRIPLINE MATERIAL DATA

	D5880	CU217
DIELECTRIC CONSTANT (10 GHz)	2.20 ±0.02	2.17 ±0.02
DISSIPATION FACTOR (10 GHz)	0.0009	0.0009
DIMENTIONAL CHANGE AFTER ETCH	NOT SPECIFIED	2×10^{-4} CM/CM
COEFFICIENT OF THERMAL EXPANSION (M/M/°C @ 35°C)	X 0.05×10^{-3} Y 0.12×10^{-3} Z 0.39×10^{-3}	X 0.030×10^{-3} Y 0.030×10^{-3} Z 0.350×10^{-3}

2078-3

The Institute for Interconnecting and Packaging Electronic Circuits (IPC) is presently circulating a proposed standard "Specification for Plastic Sheet, Laminated, Clad or Unclad, for High Frequency (Microwave) Interconnections." This document contains not only the glass/PTFE materials but also polyolefin, cross-linked polystyrene, polysulfone and polyphenylene oxide (PPO). While many of these materials are not applicable for most military applications, this document, if adopted, may help organize the great variety of materials and their characteristics. It would be of great help to both the manufacturer and user. A similar type of document on copper cladding has been adopted by the Department of Defense in place of a Military Specification.

COPPER CLADDING

The dielectric materials used for stripline circuits are typically clad with copper foil, although other types of cladding are also available. The circuit is formed by etching away the copper except for the desired circuit configuration. The copper foil thus becomes the principal circuit conductor and its characteristics are important in obtaining the desired performance. The copper must be a good conductor to provide low insertion loss. It must also adhere to the dielectric material so it does not peel during the etching and subsequent processing.

The copper cladding requirements were defined by MIL-F-55561B dated 9 May 1977, "Foil, Copper, Cladding for Printed Wiring Boards." This specification has been supplemented by ANSI/IPC-CF-150E, dated May 1981. This document, entitled "Copper Foil for Printed Wiring Applications," was written by the Copper Foil Subcommittee of the Raw Materials Committee of the Institute for Interconnecting and Packaging Electronic Circuits. On 1 October 1981 this non-Government document was approved for use by the Department of Defense. This standard is much more detailed in engineering requirements than an earlier one (MIL-F-55561B), especially as to the physical properties of the copper.

Two types of copper cladding have been used for stripline circuits; electrodeposited copper and rolled copper. Electrodeposited copper is formed by the direct electrodeposition of copper on to a moving smooth cathode, from which it is continuously stripped. Thus, the side toward the cathode is

smooth, while the other surface is rough and therefore adheres to the dielectric material. Rolled copper, referred to as wrought copper in ANSI/IPC-CF-150E, is formed by the rolling of copper ingots. This copper would thus have two smooth surfaces. To be able to bond this to the dielectric, one side is chemically treated to provide a rougher surface.

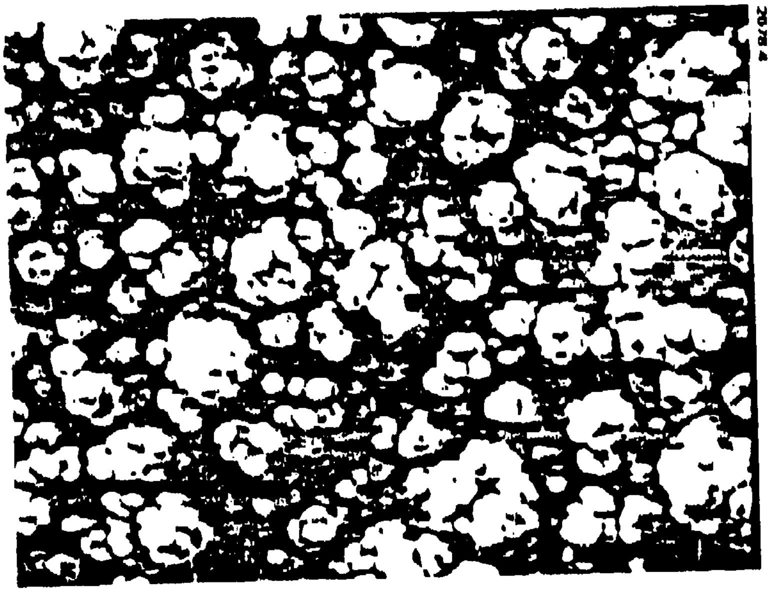
The characteristics of the copper surfaces are very evident from the scanning electron microscope photographs in Figures 3 through 6. Figure 3 shows the electrodeposited copper at two tilt angles from the vertical, 0 and 45 degrees. The magnification is 2000 times. The surface is very rough and appears as stacks of little balls. The uniformity of the surface, at least in the sample examined, was very good. There was no discernible difference in roughness in various parts of the sample.

Scanning electron microscope photographs of a sample of rolled copper are shown in Figure 4. The grain structure of the roughness is much finer than the electrodeposited copper. There was, however, a noticeable variation in roughness across the surface of the sample. There were also very large grains appearing randomly across the surface, as can be seen in the center of Figure 4b.

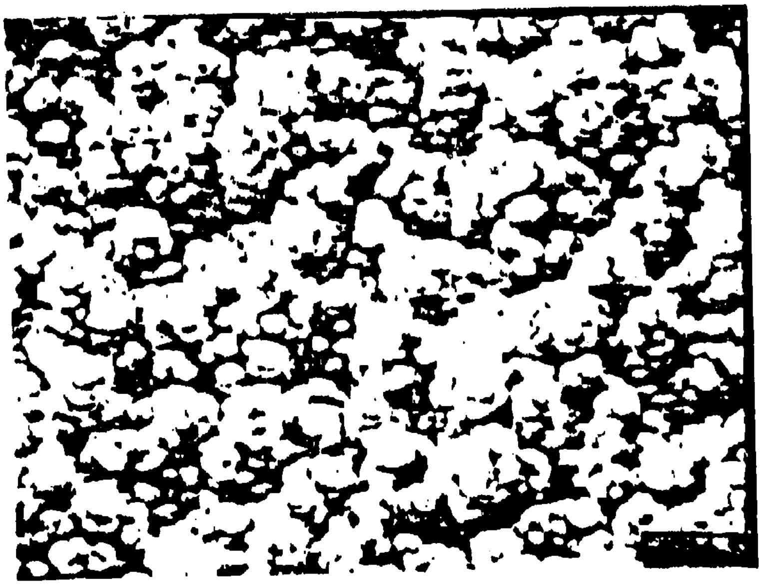
The outer surface of the copper cladding is much smoother, as can be seen in Figure 5. The electrodeposited copper shows nonuniformities that probably represent the surface of the cathode on which the copper was plated. The direction of the roll is very evident on the rolled copper surface.

The copper cladding was stripped, or pulled, from two pieces of clad dielectric material. The electrodeposited copper pulled off in a rather uneven fashion. In some spots the copper pulled dielectric material from the sample. In other places, it came off rather easily. The photo of the electrodeposited copper in Figure 6 was taken at a spot where the copper was easily removed. An examination of the surface appears to indicate that the rough surface was not deeply pressed into the dielectric but was more of a surface attachment. The rolled copper, in contrast, seemed to be more uniformly attached across the surface of the sample.

The analysis in the following section of this report shows that the surface roughness of the copper cladding has an effect on the performance of stripline circuits. The effects of surface roughness are also evident in the experimental data discussed later in the report.

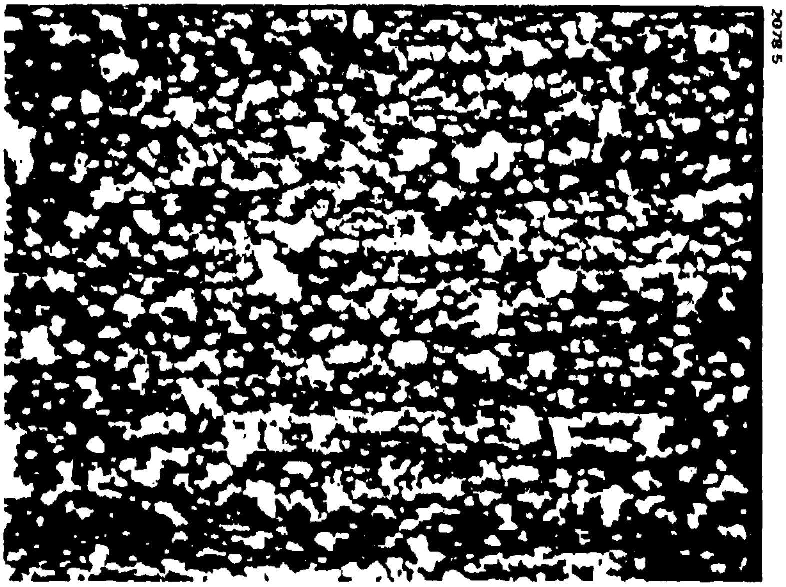


a) TILT ANGLE 0 DEGREES



b) TILT ANGLE 45 DEGREES
MAGNIFICATION 2000X

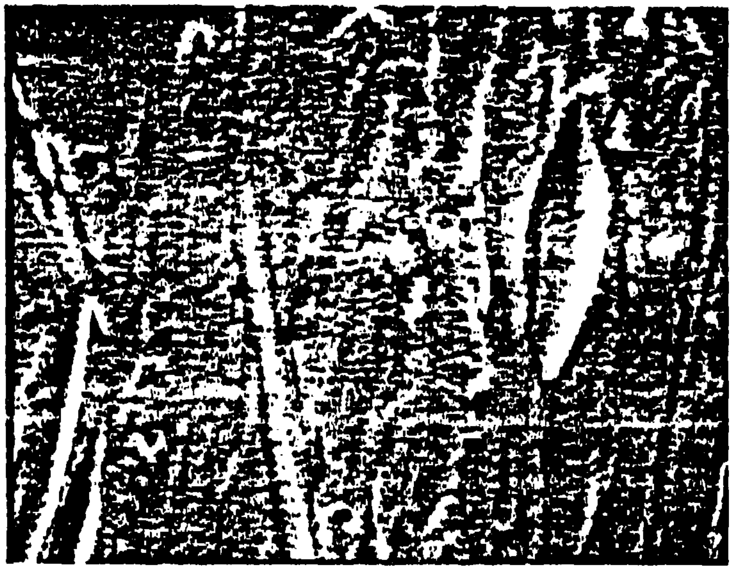
Figure 3. Electrodeposited Copper



a) TILT ANGLE 0 DEGREES

b) TILT ANGLE 45 DEGREES
MAGNIFICATION 2000X

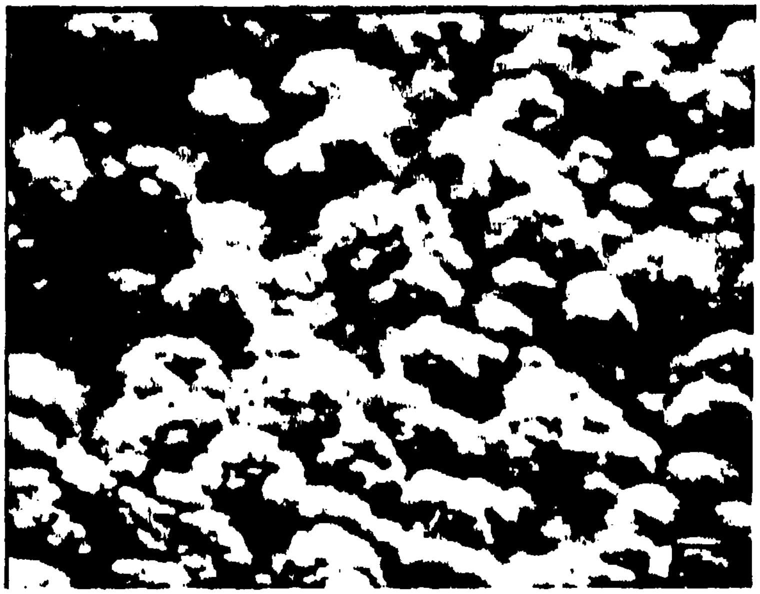
Figure 4. Rolled Copper



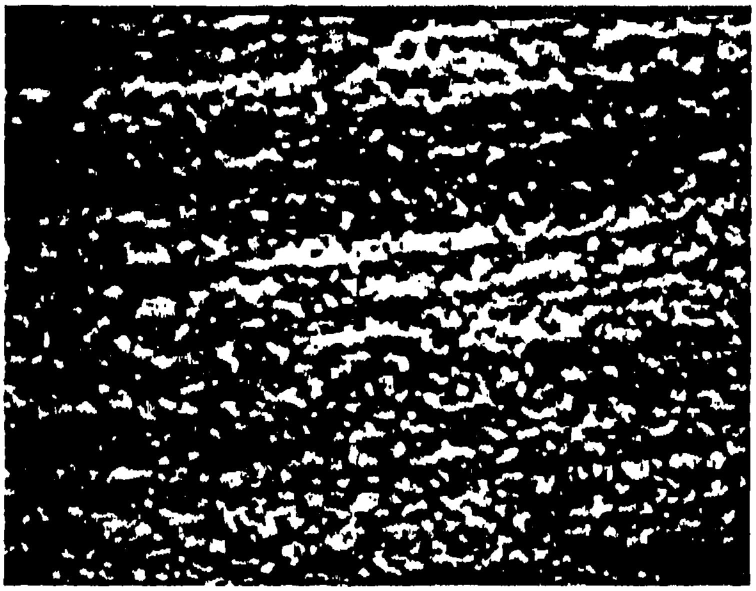
a) ELECTRODEPOSITED

b) ROLLED COPPER
MAGNIFICATION 2000X

Figure 5. Outer Surface of Copper



a) ELECTRODEPOSITED COPPER



b) ROLLED COPPER

MAGNIFICATION 2000X

Figure 6. Copper Stripped from Dielectric

SECTION V

SURFACE ROUGHNESS OF COPPER CLADDING AFFECTS PERFORMANCE

INTRODUCTION

It has long been recognized that the insertion loss of stripline circuits is a function of the condition of the surface of the copper cladding. More recently it has also been noted that the surface roughness can affect other performance parameters in broadband couplers. Most noticeable is a reduction in the isolation that could be achieved in broadband couplers.

Little noted experiments conducted by Rehnmark[1] provided quantitative data on the effect of surface roughness. Rehnmark was investigating methods of improving isolation in broadside coupled, single section, directional couplers. Poor isolation in these couplers was caused by unequal phase velocities of the even and odd modes. He conducted a series of experiments and found the following:

1) Apparent dielectric constant of the dielectric material, based on velocity of propagation measurements, depends on how the copper is bonded to the dielectric.

2) Rough surface of the electrodeposited copper increased the apparent dielectric constant by 10 percent above that measured with smooth brass circuits.

3) A series of couplers designed to operate at different frequencies showed that there was no change in the effect over the 1 to 18 GHz frequency band.

4) The ratio of the even and odd mode phase lengths was a function of the thickness of the center board and the degree of coupling.

These test results, coupled with similar observations of broadband couplers at Hughes, provided the impetus to search for an analytical solution. The boundary value problem of an electromagnetic wave traveling between rough surfaces and its effect on broadband stripline circuits was analyzed by Kreinheder[2].

BOUNDARY VALUE PROBLEM

Barlow[3] has shown that two highly reactive parallel surfaces can support a surface type wave that has a number of unique properties. Wait[4] solved for the propagation of the shielded surface wave, assuming the surface impedance of the boundaries is highly inductive and that the spacing between the surfaces is large. This analysis uses a similar approach but assumes that the spacing is small and the surfaces are identical.

Consider the electromagnetic wave as a TM (transverse magnetic) wave propagating in the X direction between two parallel surfaces, of infinite extent, in the XZ plane and separated by the distance d, as shown in Figure 7.

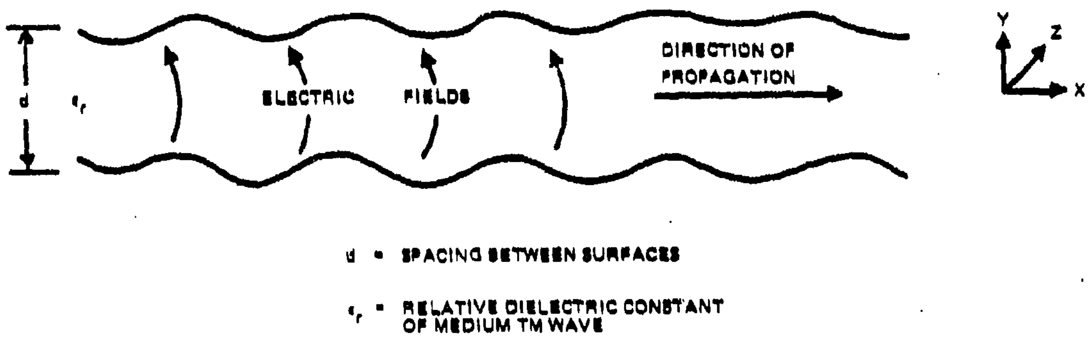


Figure 7. TM Wave

The problem is to find an expression for the velocity of propagation, or effective dielectric constant, as a function of the surface roughness.

The propagation constant, β, in the X direction is

$$\beta^2 = u^2 + k^2 \tag{1}$$

where u is the propagation constant in the y direction and k is the propagation constant for the dielectric material. Solving Maxwell's equations, for the region between the surfaces, with the assumption that both surfaces are identical and have a surface impedance Z_s, gives

$$u^2 \approx -\frac{i2\epsilon\omega Z_s}{d} \tag{2}$$

To solve for μ it is necessary to obtain an expression for the surface impedance Z_s.

IMPEDANCE OF A ROUGH SURFACE

The statistically rough surface has been analyzed by T. B. A. Senior[5]. Senior assumed that the surface is of infinite extent and obtained by perturbation of a plane. The equation for the surface is taken as $y = f(x,y)$ with the height and scale of the variation of f about its mean denoted by g and ℓ, respectively, as shown in Figure 8.

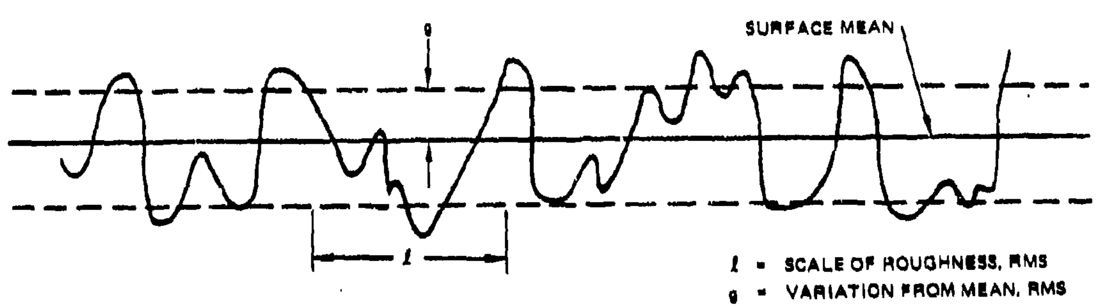


Figure 8. Surface Roughness Parameters

Since kl is less than unity for the rough surface of the copper cladding, Senior's solution reduces to

$$Z_s = i \frac{\sqrt{\pi}\, k^2 g^2}{\epsilon_0\, \omega \ell} \tag{3}$$

INCREASE IN EFFECTIVE DIELECTRIC CONSTANT

The normalized effective dielectric constant ϵ_{eff} can be related to β and μ by

$$\epsilon_{eff} = \left(\frac{\beta}{k}\right)^2 = 1 + \left(\frac{\mu}{k}\right)^2 \tag{4}$$

substituting (3) into (2)

$$\mu^2 = \frac{2\sqrt{\pi}\,\epsilon_r\, g^2\, k^2}{d\ell} \qquad (5)$$

The increase in the effective dielectric constant due to surface roughness is thus

$$\Delta\,\epsilon_{eff} = \frac{2\sqrt{\pi}\,\epsilon_r\, g^2}{d\ell} \qquad (6)$$

Note that $\Delta\,\epsilon_{eff}$ is not a function of frequency and is inversely proportional to the distance between the surfaces.

CALCULATED EFFECTIVE DIELECTRIC CONSTANT

The increase in the effective dielectric constant for material clad with electrodeposited copper can now be calculated. Using the scanning electron microscope photographs of Figure 3 shown in Section IV, the approximate roughness values of g and ℓ of Equation 6 can be determined. The photographs at 0 and 45 degrees to the perpendicular help to give some perspective to the depth. From these photographs and from other references such as Reference 6, a typical value of g would be 0.0001 inch and ℓ would be 0.00025 inch. Figure 9 shows the percentage increase in the effective dielectric constant as a function of d, the dielectric thickness.

The values shown in Figure 9 are less than the 10 to 15 percent increase reported by Rehnmark for 0.005 inch spacing in stripline circuits. He did not, however, define the surface roughness so a direct comparison cannot be made. The values are consistent, however, with recent experience using couplers with a 0.0075 inch thick center board and 0.070 inch ground plane spacing. Calculations indicate that to obtain the observed performance, there was an increase in effective dielectric constant of the odd mode of about 5 percent compared with the even mode for the tightly coupled center sections.

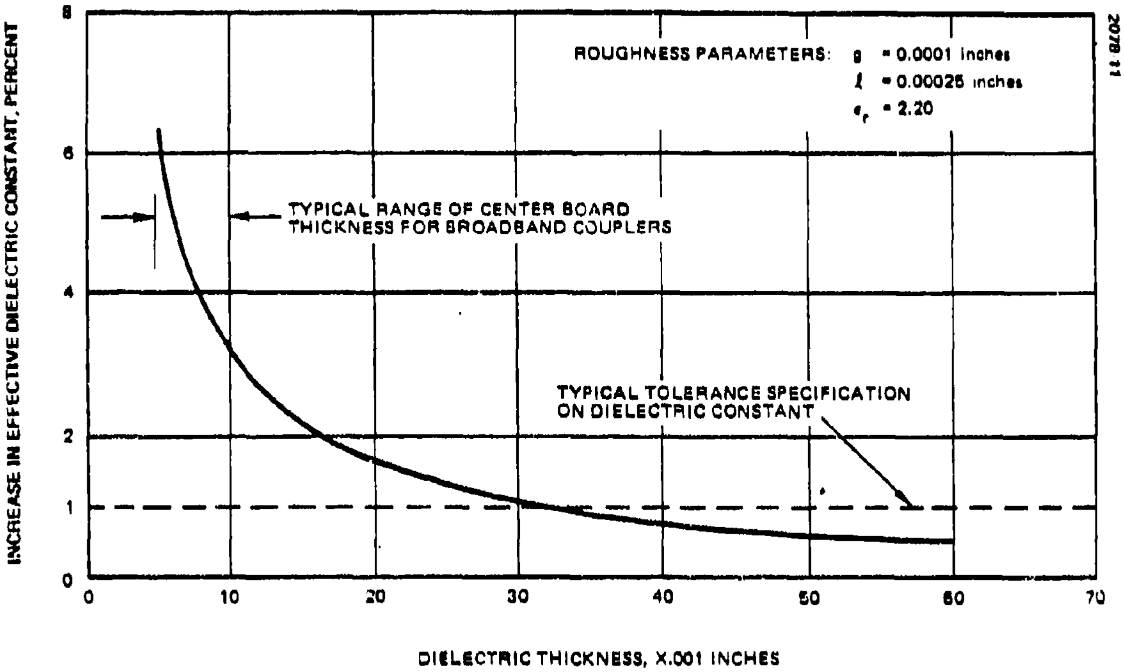


Figure 9. Increase in Effective Dielectric Constant versus Dielectric Thickness for Electrodeposited Copper

The difficulty of measuring the surface roughness is the great limitation on accurately calculating the increase in effective dielectric constant. It is also possible that Senior's model of an undulating, essentially smooth surface does not fully reflect the impedance of the jagged, rough surface of the electrodeposited copper.

EFFECT OF SURFACE ROUGHNESS ON BROADBAND COUPLERS

Broadband multisection couplers have very tight coupling in the center section. Tight coupling is achieved by using very close spacing between the inner conductors, as shown in Figure 10. Typical stripline construction has the inner conductors etched on each side of the dielectric center board. The rough copper surfaces thus face each other through the thin dielectric center board. The smooth outer copper surfaces face the more distant outer ground planes. The odd mode, shown in Figure 10, propagates between the two closely spaced, rough inner conductors. The odd mode thus propagates at a slower

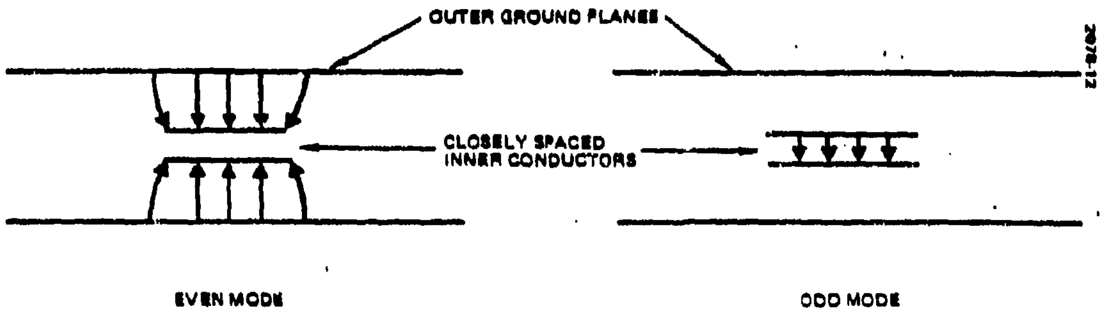


Figure 10. Even and Odd Mode Electric Field Configuration

velocity than the even mode, seeing what appears to be an increase in effective dielectric constant. The difference in velocity of the even and odd modes causes the coupler to have poor isolation and phase characteristics.

There is an impedance associated with each mode. Let Z_e be the impedance of the even mode and Z_o the impedance of the odd mode. The coupling, C, between the two inner conductors, for a length of line one quarter wavelength long, is

$$C = \frac{Z_e - Z_o}{Z_e + Z_o} \tag{7}$$

A transmission line can be represented by the lumped constant analogy of series inductance, L, and shunt capacitance, C, as shown in Figure 11. The characteristic impedance of the line, Z, is

$$Z = \sqrt{\frac{L}{C}} \tag{8}$$

and the velocity of propagation, v, is

$$v = \frac{1}{\sqrt{LC}} \tag{9}$$

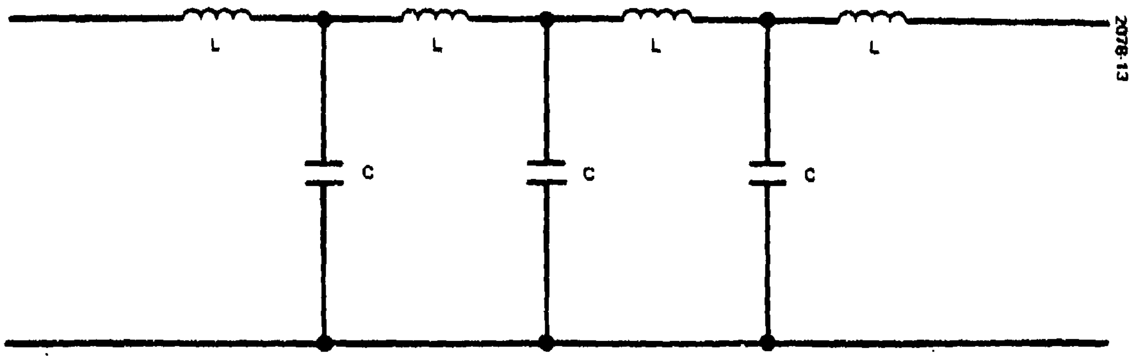


Figure 11. Lumped Constant Transmission Line Analogy

Consider now, that a different circuit would represent the even and the odd modes. If the L of the odd mode circuit were increased, because of the surface roughness, without a change of the capacitance, the impedance of the odd mode would increase and the velocity of propagation would decrease. If this change occurred only in the odd mode circuit, the odd mode impedance would increase in relationship to the even mode. As can be seen from the coupling, Equation 7, this would then cause a reduction in coupling.

The effect on coupling was evident in the test results presented later in this report. In multisection couplers only the center section is very tightly coupled. Outer sections are progressively more loosely coupled. The effect of an increase in surface roughness, then, is a decrease in coupling with the largest decrease in the center of the frequency band and only a small decrease at the band edges.

SECTION VI

MEASUREMENT OF DIELECTRIC CONSTANT

MIL-P-13949F TEST METHOD

Appendix A of MIL-P-13949F, 10 March 1981, describes the test method for measuring the dielectric constant and dissipation factor of stripline materials at X-band. The title describes the procedure as for use with GR and GX laminates. However, it is used for all types of materials that are measured at X-band. This method has proven to be very useful. The manufacturer and user can make measurements with their own test circuits, built to drawings in Appendix A, and generally agree on the measurements.

The test fixture, built at Hughes for this program, is shown in Figure 12. Unclad pieces of dielectric material are stacked on each side of the resonant or circuit. The ground planes are attached and it is then placed in a vice and pressure is applied until 1000 lbs/in^2 is obtained. The resonant frequency and bandwidth are then measured. The dielectric constant and dissipation factor are computed from formulas in Appendix A.

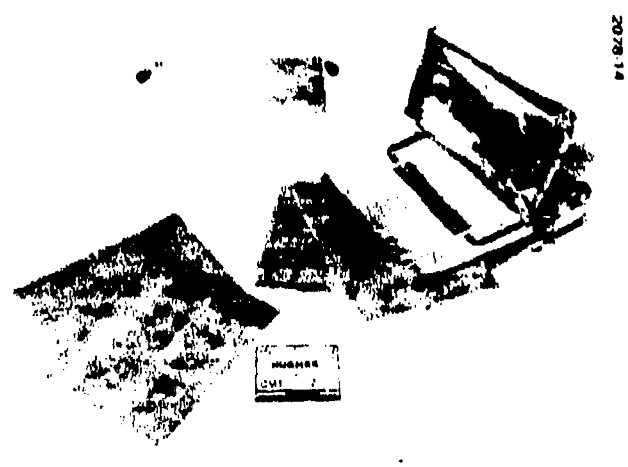


Figure 12. MIL-P-13949 Test Fixture

This test method has a number of shortcomings and limitations when applied to stripline materials for broadband couplers. The problems are:

1) The test circuit is designed for four 1/32 inch, or two 1/16 inch dielectric sheets for an overall stack of 0.130 ±0.010. This puts a great limitation on the thickness of materials that can be measured, even excluding certain relatively standard thicknesses of material; for example, 0.045 inch material.

2) The center board of the couplers used as test circuits for this program were 0.0075 inch thick with a tolerance of ±0.0006 inch. The number of boards used could thus vary from 15 to 20 depending on the exact material thickness and the height of the stack used. Since each test board is 2.7 by 2.0 inches, if 17 boards were used, 91.8 in^2 of material would be required. The standard sheet size for Duroid 5880 used for the test circuits is 16 by 10 inches or 160 in^2. Thus, more material would be used for dielectric constant measurement than would be available for circuit fabrication.

   The use of many boards may also cause errors resulting from entrapped air. Measurements on boards indicate that they are not perfectly flat. Most boards vary ±0.0001 inch within a few inches. Variation as great as ±0.0003 inch have been noted. It thus appears possible to have a measurement error of 2 percent caused by entrapped air when the material tolerance is specified at 1 percent.

3) The test circuit measures an average dielectric constant along the 1.500-inch resonator but there could be large dielectric constant variations throughout the material. Typical broadband coupler circuits are dependent not only on the desired dielectric constant but also on uniformity of the dielectric constant across the whole circuit. Any variation of dielectric constant should average out over a very small fraction of a wavelength. The test for uniformity is difficult and should be a nondestructive test capable of being conducted on the clad material.

4) The test circuit is used primarily to test bulk material characteristics and does not include any test of the effects of the copper cladding. The copper cladding can have a number of effects on the

stripline circuit performance. The insertion loss can be increased because of a lossy surface finish on the copper. The copper can also cause a change in the phase velocity of the wave as described in Section V of this report. Hence, it is useful to have some test that will indicate the condition of the copper.

SQUARE CAVITY TEST METHOD

It is evident that the test method of MIL-P-13949F has a unique place in that, even though limited in scope, it is widely used, relatively easy to use and well understood by those who use it. It will not be an easy test to replace and, indeed, should probably not be replaced but should be augmented in special cases with other types of tests. This test method should have the following desirable features:

1) Measure the dielectric constant and loss tangent regardless of the material thickness.
2) Make measurements with copper clad material.
3) Use a small size sample.
4) Include the capability to make measurements at different microwave frequencies.
5) Use easy to implement test methods.
6) Minimize sample preparation.

A literature search was made on methods of measuring dielectric constant and many technical papers were reviewed.[6-30] Most techniques are not applicable to the measurement of stripline materials. One test method, which uses square dielectric cavities[10, 15 - 18] has the desirable features listed above. This method has been used to measure the high dielectric constant substrates for microwave integrated circuits. The use of this same technique for the low dielectric constant stripline materials, however, is dependent on the ability to achieve a measurable resonant response in samples as thin as 0.005 inch. A waveguide type cavity is made (from the copper clad dielectric material) by cutting a 1-inch square and then plating the exposed dielectric edges. The small sample can be accurately machined to a precise square. The edge plating completely encloses the dielectric without any air

gaps so the dimensions of the cavity are precisely known. Coupling apertures are cut into the plating on opposite sides of the plated test piece. The apertures are small to minimize the effects of the reactance coupling apertures on the resonant frequency. The apertures are placed in the center of the edge to maximize coupling to the lowest order mode.

The cavities will resonate when there is an integral number of half wavelengths in the 1-inch dimension. Since the apertures are in the center, only modes having an odd number of half wavelengths in that direction are of interest. The modes with an even number of half wavelengths have a null at the apertures and there is no coupling to them. The number of half wavelengths in the opposite direction can be any integer value.

The frequency of the cavity resonances can be calculated from:

$$f = \frac{c}{2\sqrt{\epsilon_r}} \sqrt{\frac{p^2}{a^2} + \frac{q^2}{b^2}} \qquad (10)$$

where:

f = resonant frequency

C = velocity of light

ϵ_r = relative dielectric constant

p = number of half wavelengths in side of length a

q = number of half wavelengths in side of length b

Table 2 shows the modes that would be excited and the resonant frequencies of the modes assuming a dielectric constant of 2.20 and a and b dimensions of 1.000 inch. There are a number of resonances that occur in the 2 to 18 GHz band so the dielectric constant should be able to be determined at a number of different frequencies.

A test fixture, shown in Figure 13, was made to test 1-inch square plated samples of the stripline materials. SMA connectors are used for input and output connections to the test equipment. The connector center pin connects to the top of the cavity at the aperture, by means of a pressure contact.

TABLE 2. CALCULATED RESONANT FREQUENCIES

MODE DESIGNATION		CALCULATED RESONANT FREQUENCY, $\epsilon_r = 2.2$ a = b = 1.000 INCH
p	q	
1	1	5.63 GHz
1	2	8.89 GHz
1	3	12.58 GHz
3	1	12.58 GHz
3	2	14.34 GHz
1	4	16.40 GHz
3	3	16.98 GHz

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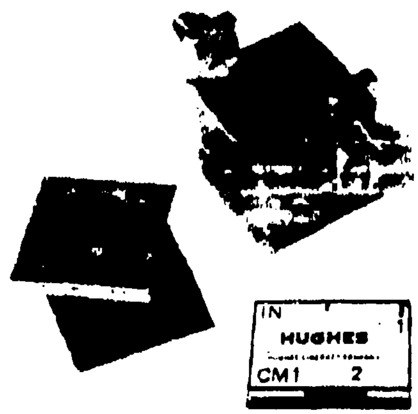

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Figure 13. Test Fixture for 1-inch Square Resonators

Figure 14 is a swept frequency, insertion loss plot across the 2 to 18 GHz band. The material is RT/Duroid 5880, 0.0075 inch thick, clad with 1 ounce rolled copper. Each of the resonances is defined by the p and q mode numbers. The approximate frequency of resonance is also indicated. Note that these results are very close to those predicted in Table 2.

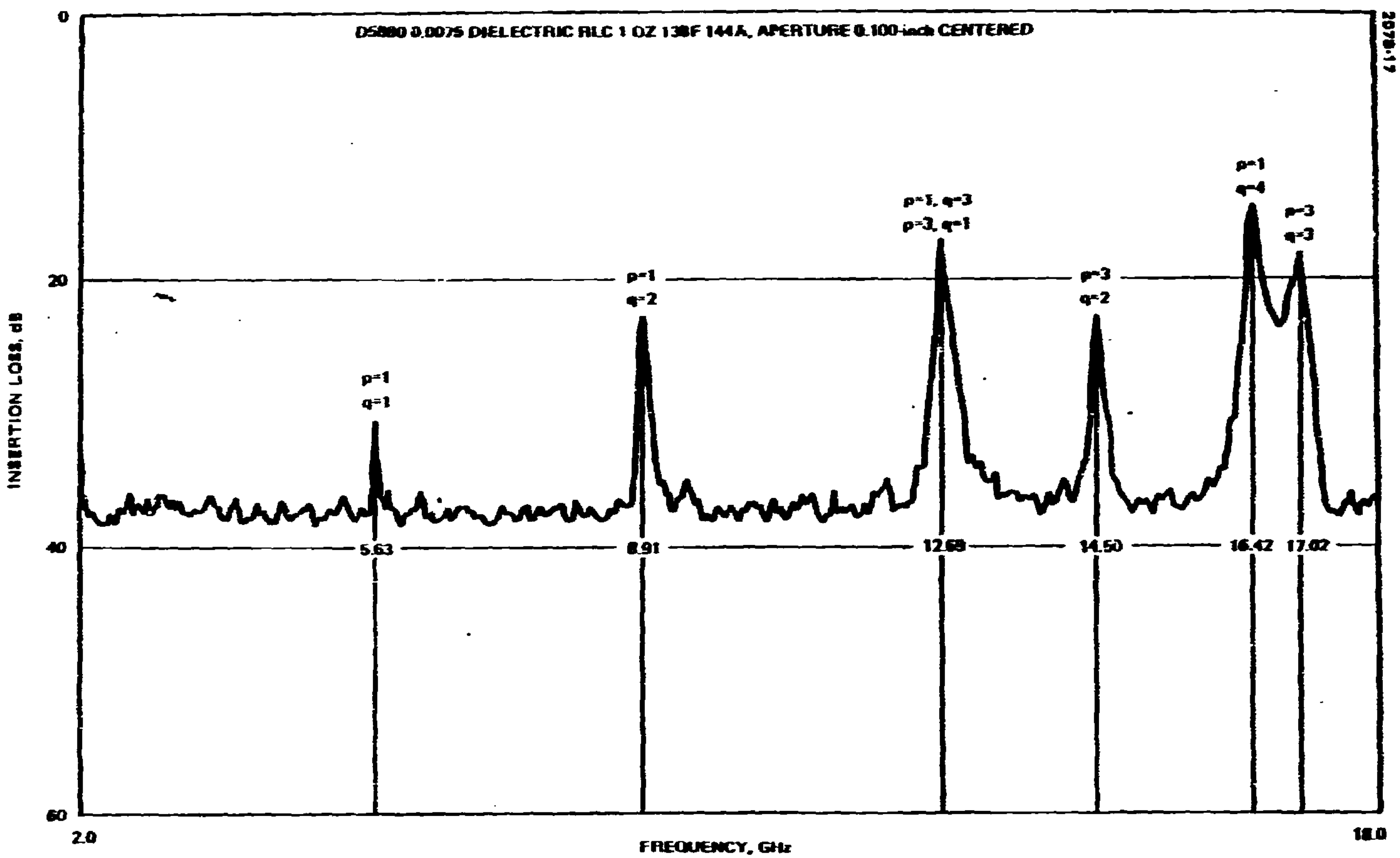


Figure 14. Swept Frequency Insertion Loss Plot

Since the resonant frequency can be determined from sweep insertion loss data and the integer values of p and q are known from the frequency, it would seem that the dielectric constant should be able to be determined from Equation 7. This equation, however, holds only if the Q of the circuit is infinite. Since the resonances being considered have a relatively low Q, an adjustment to the measured frequency must be made[31]. If f_m is the measured frequency, the corrected frequency f to be used in Equation 7 is:

$$f = \frac{f_m}{\left(1 - \frac{1}{2Q}\right)} \tag{11}$$

where Q is the measured Q of the resonance. This phenomenon is caused by an apparent shift in resonant frequency resulting from wall losses.

Figures 15 and 16 show the measured response of two different resonators where the resonances are measured at 8 and 12 GHz. The frequencies are indicated at the peak of the response and the 3 dB points. Also included in the figure is the calculation of the Q, the corrected resonant frequency, and the calculated dielectric constant. It is interesting to note that the calculated dielectric constant is slightly higher at the higher frequency and also that the dielectric clad with electrodeposited copper (EDC) has a higher apparent dielectric constant than the material clad with rolled copper (RLC).

The effect of the electrodeposited copper versus the rolled copper can be seen in Figure 17. Seven different samples were measured and the dielectric constant computed from the resonance response. The samples with rolled copper consistently showed lower effective dielectric constants than those with electrodeposited copper. Figure 17 also shows the increase in the measured dielectric constant for the thinner materials. These data are consistent with and tend to verify that there is an increase in effective dielectric constant with surface roughness and that the increase is inversely proportional to the thickness of the dielectric material.

There is, however, additional work that must be performed to perfect this technique and obtain accurate measurement of the effective dielectric constant of the stripline material. The size of the coupling aperture does effect the

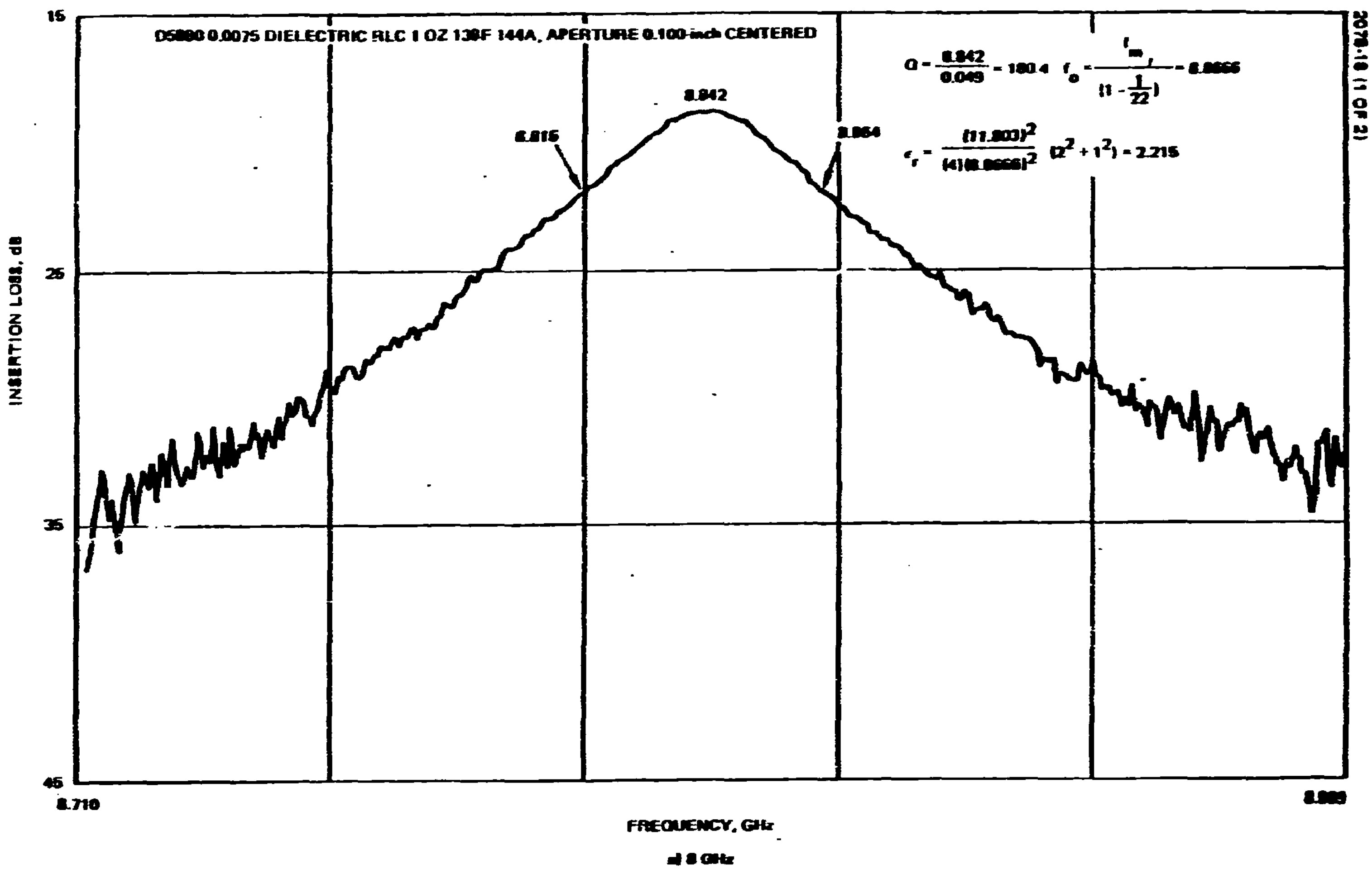


Figure 15. Calculation of Dielectric Constant from Resonance Curves, Sample 2B

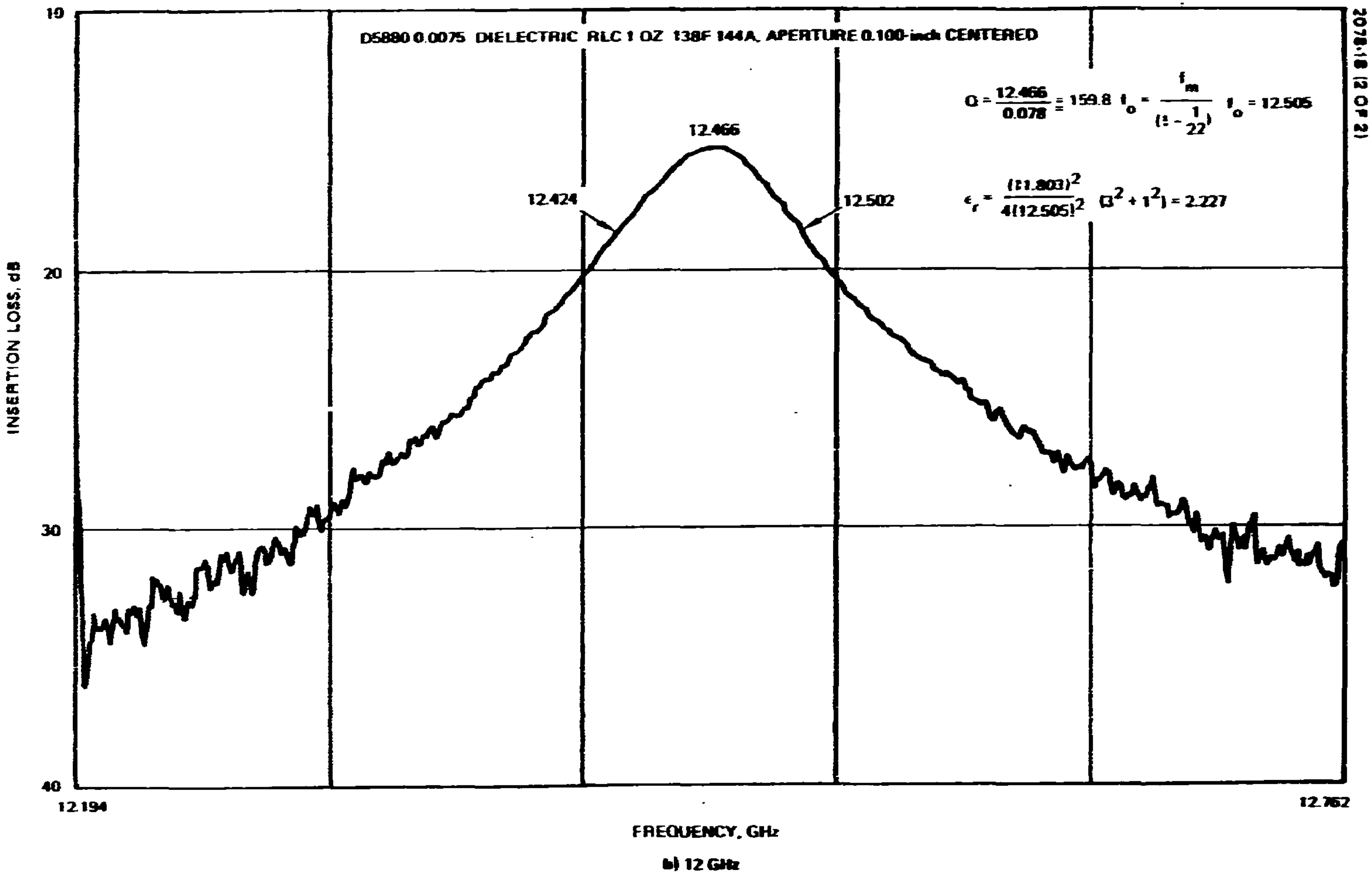


Figure 15 (Concluded).

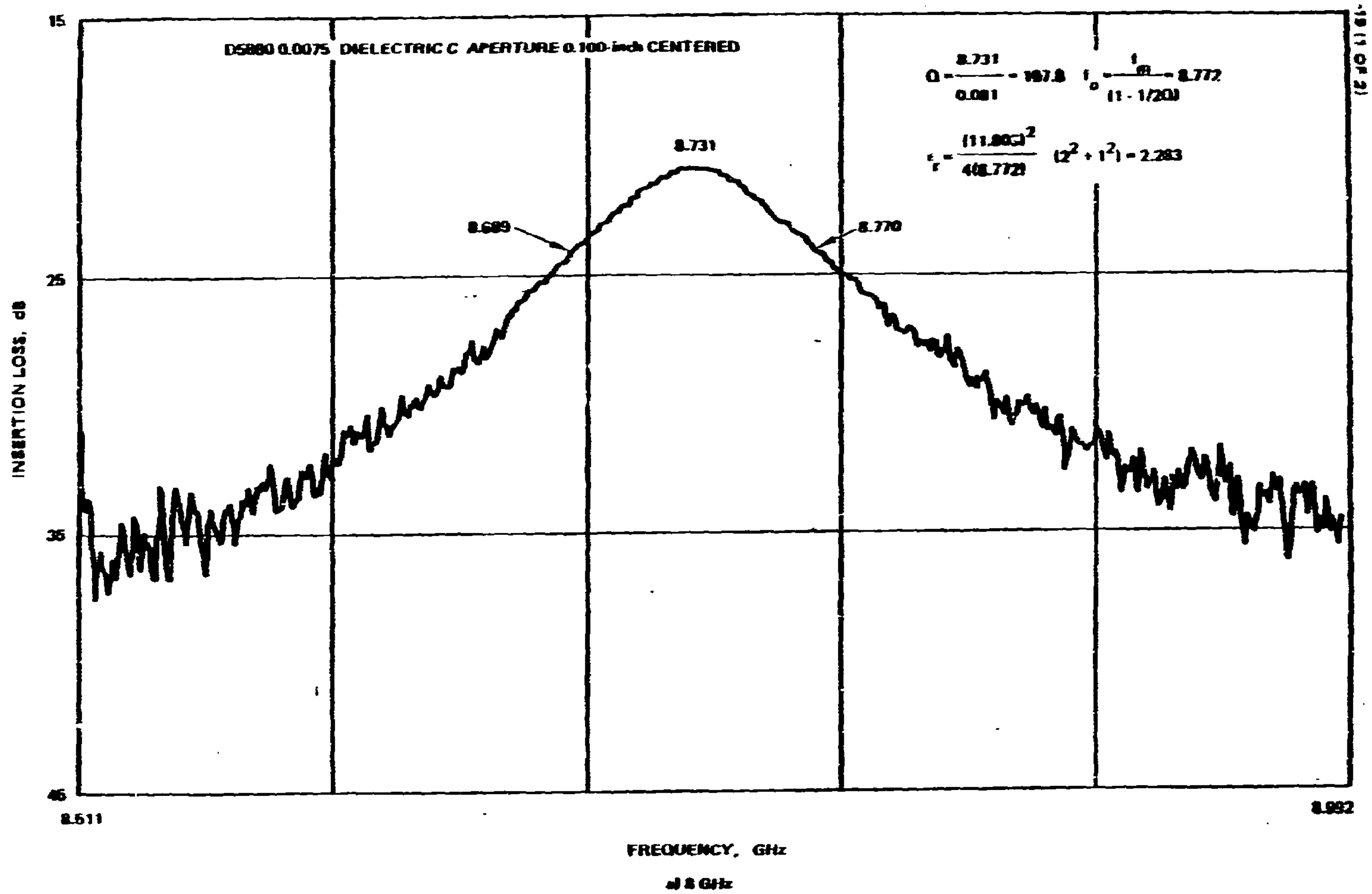


Figure 16. Calculation of Dielectric Constant from Resonance Curves, Sample 8A

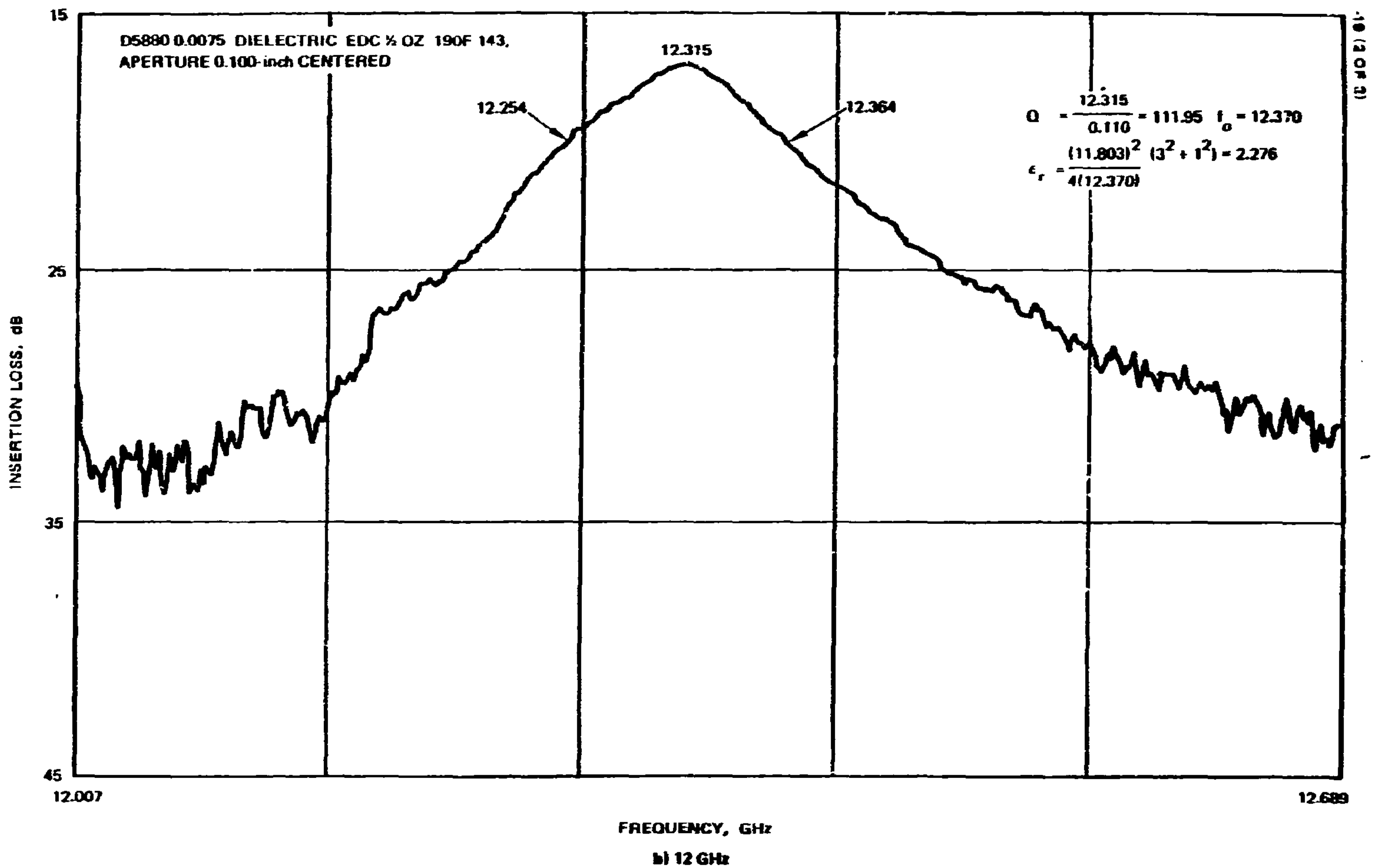


Figure 16 (Concluded).

resonant frequency. The low dielectric constant values of the 0.031-inch materials in Figure 17 is believed to be caused by oversized coupling apertures. To obtain accurate data, the coupling apertures will have to be cut to precise dimensions. An adjustment, determined experimentally, would then be made to the resonant frequency. This would be similar to the adjustment made for fringing fields that is used in the MIL-P-13949F test method.

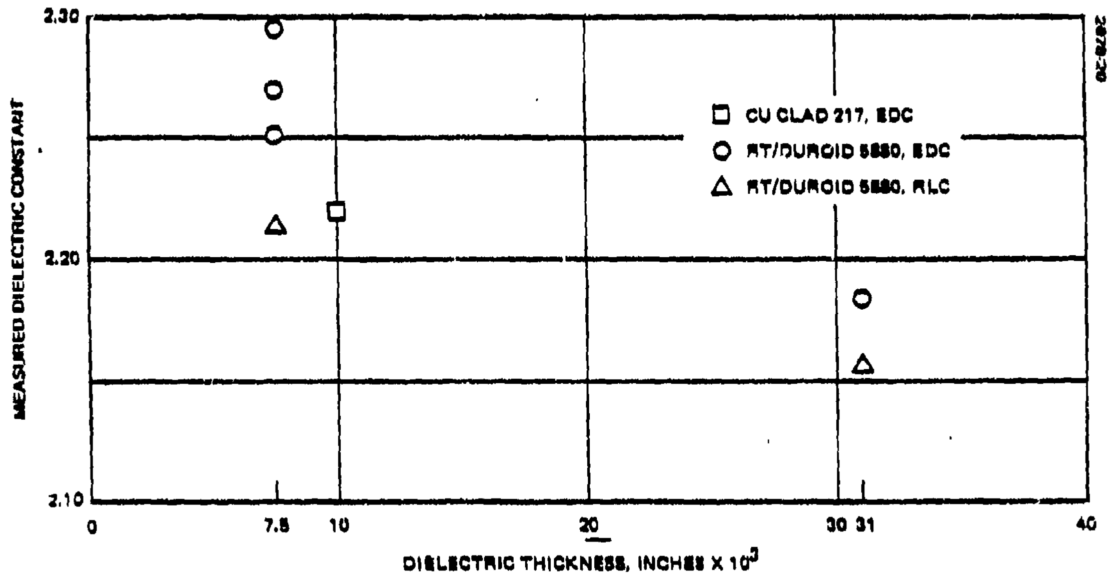


Figure 17. Effective Dielectric Constant of Test Resonators

SECTION VII
STRIPLINE TOLERANCE STUDY

The tolerance study was performed by using a combination of analytical and experimental data. The nine section coupler, used for the experimental data, is very complex. It is very difficult to calculate the effects of tolerances on the nine section coupler. Calculations were therefore made on a single section coupler and also on a five section coupler using the approximation that the outer sections were edge coupled. These calculations showed the effects of changes in dielectric thickness, line widths, line offsets, etc. The results of these calculations were especially helpful in interpreting the experimental data because of the large number of variables involved.

PARAMETERS THAT EFFECT COUPLER PERFORMANCE

Broadband Stripline Coupler Test Circuit

The test circuit used for this program is the broadband 3 dB quadrature coupler that operates over the 2 to 18 GHz frequency range. Quadrature refers to the fact there is a 90 degree relative phase shift between the outputs.

The coupler is a nine section coupler, each section being a quarter wavelength long and is similar to the five section coupler shown in Figure 18. The prototype five section coupler has an overlapping center section and outer sections that are progressively more loosely coupled. The prototype coupler has poor electrical performance because of the reactance of the abrupt steps. To reduce this effect, the multistep design is used so there are no large reactive steps. In the limit, if smaller steps were used, the coupler would have a continuous taper.

The cross section of the quadrature coupler is shown in Figure 19. There are two modes, referred to as the even and odd modes, in the coupled region and there is an impedance associated with each mode. As shown by the electric fields in Figure 19, the inner conductors have the same electric potential for the even mode but are out of phase for the odd mode. The coupling between the conductors is a function of the even and odd mode impedances. Note that for

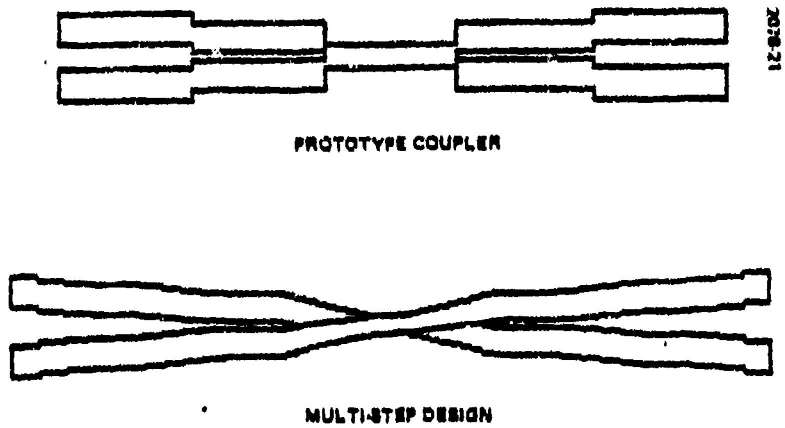


Figure 18. Five Section Quadrature Coupler

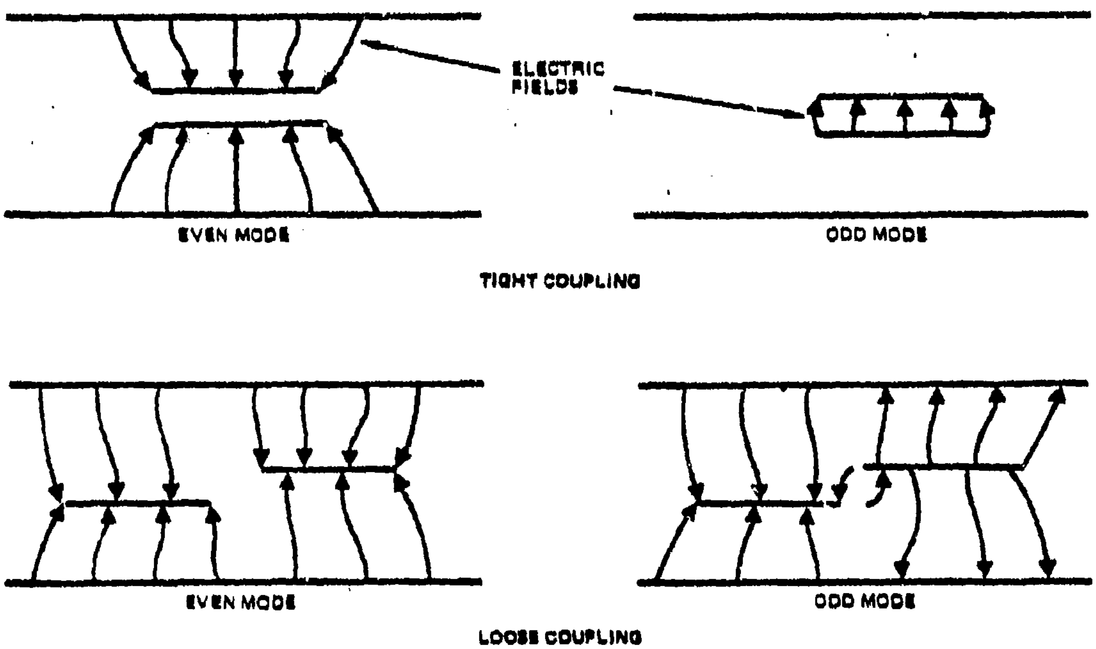


Figure 19. Even and Odd Mode Electric Fields

the tightly coupled case, the odd mode electric fields are confined between the two closely spaced conductors. The odd mode of the loosely coupled sections, in contrast, has only a fraction of the fields between the inner conductors.

Tolerances in Stripline Circuit

There are many tolerances that can affect performance of coupled stripline circuits. Control of these tolerances, to be within some bounds, is required to obtain repeatable performance. Parameters that affect performance of broadband stripline couplers are shown in Figure 20. These parameters are related to the fabrication of the stripline material or to the processing of the materials to make the stripline circuits.

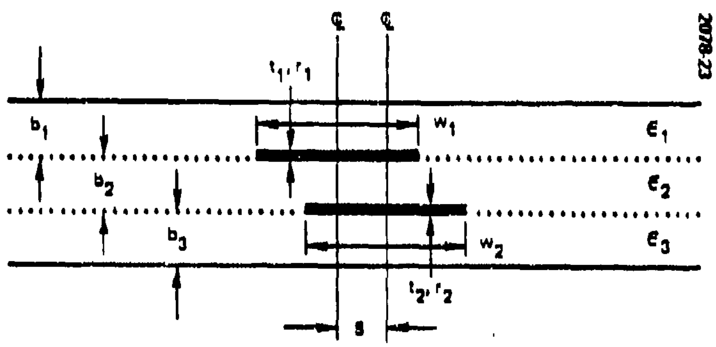


Figure 20. Parameters Affecting Performance

Dielectric Constant, ε

The dielectric constant must be controlled to some specific value and tolerance and must be within those limits from board to board. The dielectric constant must be uniform throughout the bulk of the material.

Thickness of the Material, b

The coupler performance is dependent on the thickness of the dielectric material. Thickness must be controlled and must be uniform across the material.

Imaging and Etching, w, s

The line widths, w, are determined by the exposure of the photoresist, developing of the photoresist and by the etching of the circuit. The processing must be controlled to accurately reproduce the circuits. The alignment of the photo tools will determine how accurately the offset, s, between the conductors is maintained.

Copper Cladding, t, r

The thickness, t, of the copper cladding affects the height of the three layer construction. The thickness should be uniform across the surface. Tests and theory indicate that the surface roughness, r, can have a significant effect on performance of the stripline circuits. The surface roughness of the copper should be uniform across the surface and also be consistent from sheet to sheet.

ANALYSIS OF EFFECT OF TOLERANCES

Tolerances in Single Section Coupler

An estimate of the magnitude of the affect of tolerances on broadband stripline coupler performance was obtained by analyzing the single, quarter wavelength long, coupled section. Two types of structures were analyzed: the two layer circuit with edge coupling and the three-layer circuit with broadside coupling. These stripline configurations are shown in Figure 21. Coupling is a function of the capacitance between the two inner conductors. Hence, the gap, g, for the edge coupler must be much smaller than the center board thickness, b_2, for the broadside coupler to provide the same coupling.

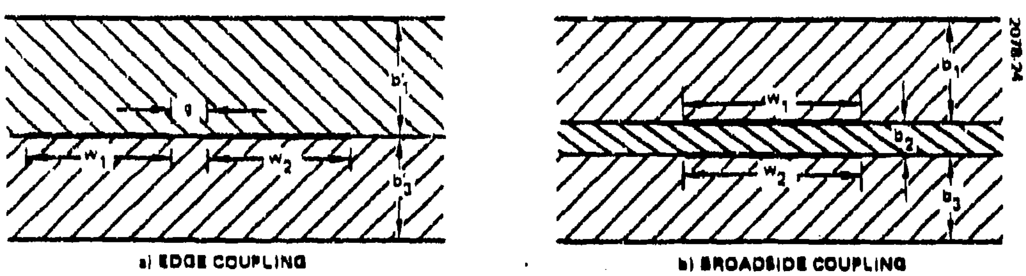


Figure 21. Stripline Configurations

The effect of tolerances on the line widths, w_1 and w_2, the center board thickness, b_2, the gap, g, and outer board thickness b_1 and b_3 are shown in Figure 22. A 3.3 dB coupler was used for the broadside coupler. A 15.5 dB coupler was used for illustration of the edge coupled case. The gap for the 3 dB edge coupler was too small to provide a meaningful comparison of tolerance effects. This also vividly demonstrates one of the reasons why a three-layer construction, rather than a two-layer construction is required for broadband stripline couplers.

Coupling is a function of the even and odd mode impedances. Figure 23 shows the effects on the even and odd mode impedances for the broadside coupled case. Since the input impedance is equal to the square root of the product of the even and odd mode impedances, the tolerances also cause a change in the circuit impedance. The change in impedance causes an increase in the input VSWR and a reduction in the isolation between the outputs. This effect is, however, quite small for the tolerances discussed here.

The effect of dielectric tolerances was considered only for the broadside coupler. The calculations for the broadside coupled lines was made using equations derived by S. B. Cohn[32]. An examination of these equations shows that the coupling is not changed by small variations in the dielectric constant. The impedance of the coupled section will change by the inverse of the square root of the dielectric constant. The effect is small; however, a 2 percent change in dielectric constant would cause a 1 percent change in VSWR and isolation.

Tolerances in Five Section Coupler

The circuit used for the empirical tolerance study is a tandem connection of two 8.3 dB couplers with nine quarter wavelength sections. The tandem connection provides a 3.0 dB coupler but reduces the coupling requirements of the center section and thus permits the use of a thicker center board. Ministep transitions are used between the sections to reduce the step reactance.

The nine section coupler with the ministep transitions is a complex structure and is very difficult to analyze for the effect of tolerances on electrical performance. To reduce the problem to a more manageable size, a

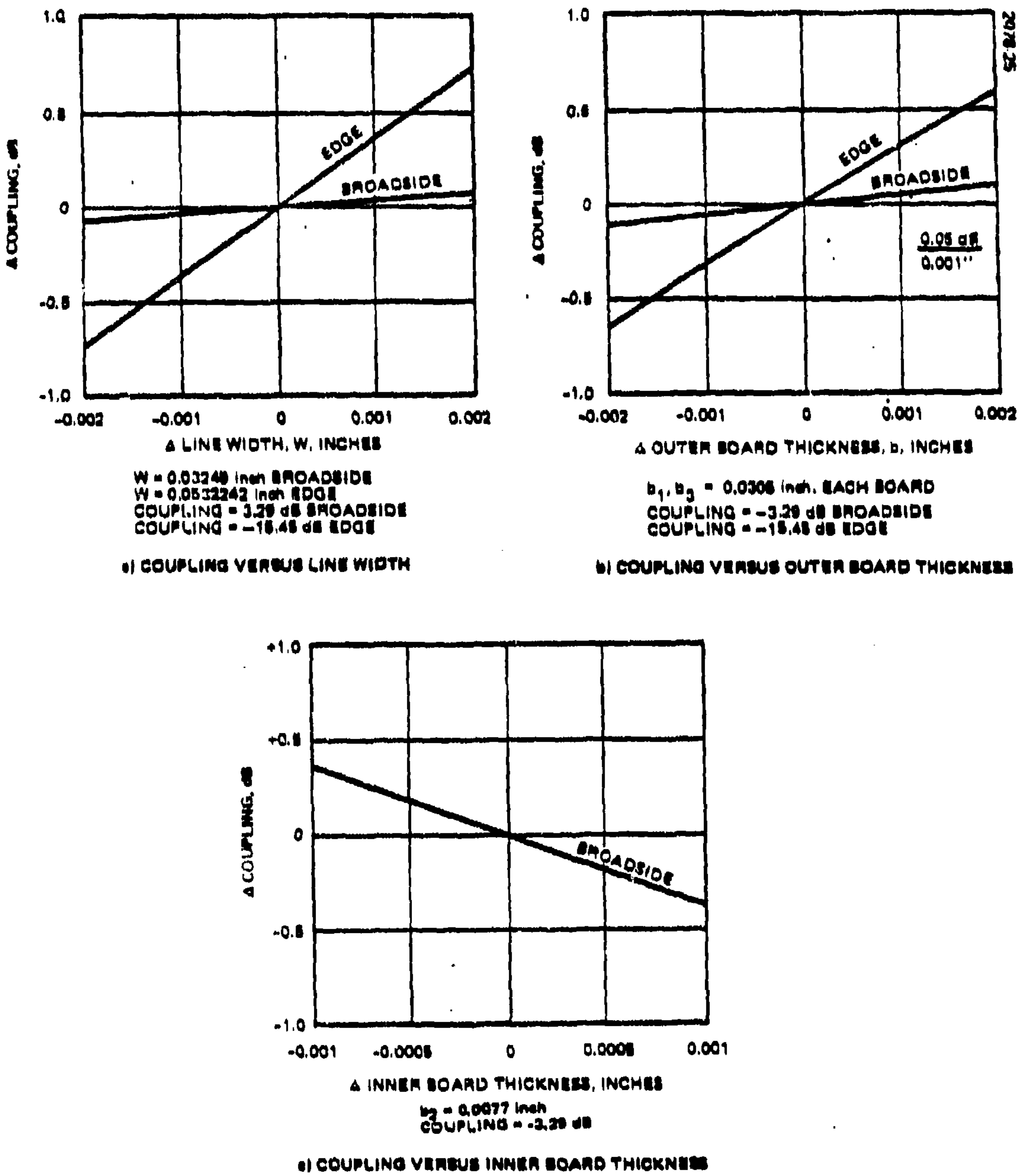
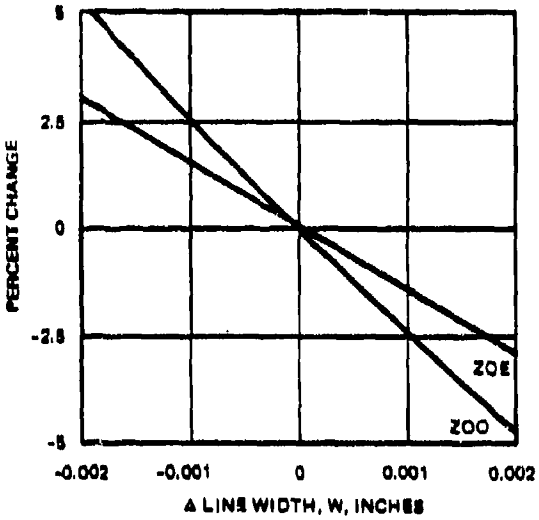
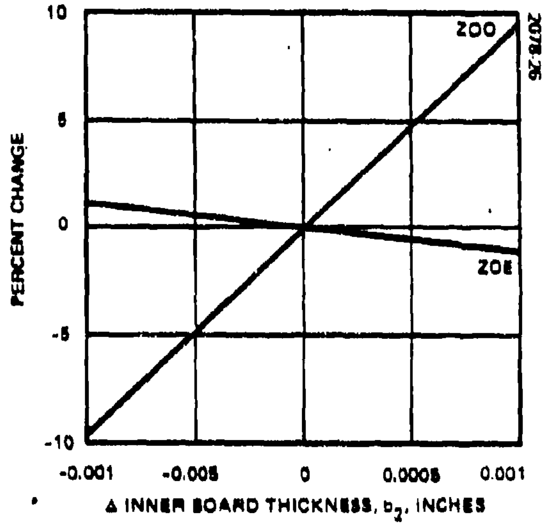


Figure 22. Coupling Variations Caused by Line Width and Board Thickness



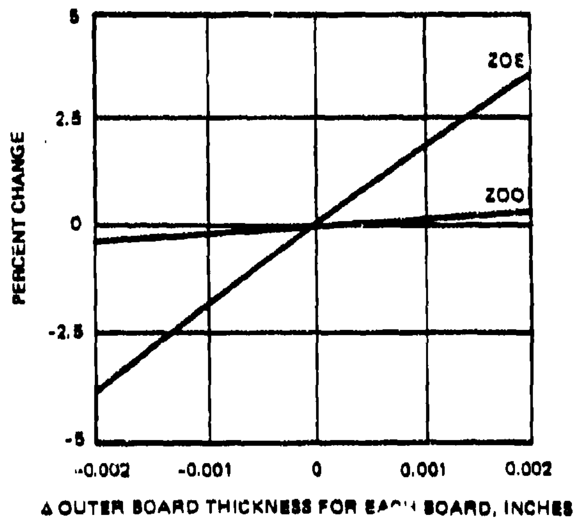
W = 0.03249 inch
ZOE = 115.440
ZOO = 21.6107
b_2 = 0.0077 inch
$b_1+b_2+b_3$ = 0.0687 inch
ϵ_r = 2.2

a) IMPEDANCE VERSUS LINE WIDTH



b_2 = 0.0077 inch
ZOE = 115.440
ZOO = 21.6107
W = 0.03249 inch
$b_1+b_2+b_3$ = 0.0687 inch
ϵ_r = 2.2

b) IMPEDANCE VERSUS INNER BOARD THICKNESS



b_1, b_3 = 0.0305 inch
W = 0.03249 inch
ZOE = 115.440
ZOO = 21.6107
b_2 = 0.0077 inch
b = 0.0687 inch
ϵ_r = 2.2

c) IMPEDANCE VERSUS OUTER BOARD THICKNESS

Figure 23. Change of Even and Odd Mode Impedances

five section coupler of about the same percentage bandwidth was chosen. The reactance of the steps between sections is neglected so only the five sections have to be analyzed.

Elegant procedures exist for the synthesis of multisection couplers. They are based on determining the even and odd mode impedances to provide the desired response. The stripline widths and offsets are then computed from the impedances. The reverse problem, to compute the response when given the line widths and offsets, is extremely difficult. This is the problem that must be handled to see the effects of the tolerances.

The five section symmetrical tandem coupler design was derived using tables by Cristal and Young[33] and is shown schematically in Figure 24. The line widths and offsets for the dielectric constraint and material thicknesses chosen were computed using a program based on the equations by J. P. Shelton[34]. A computer program was also written to plot the characteristics of the coupler.

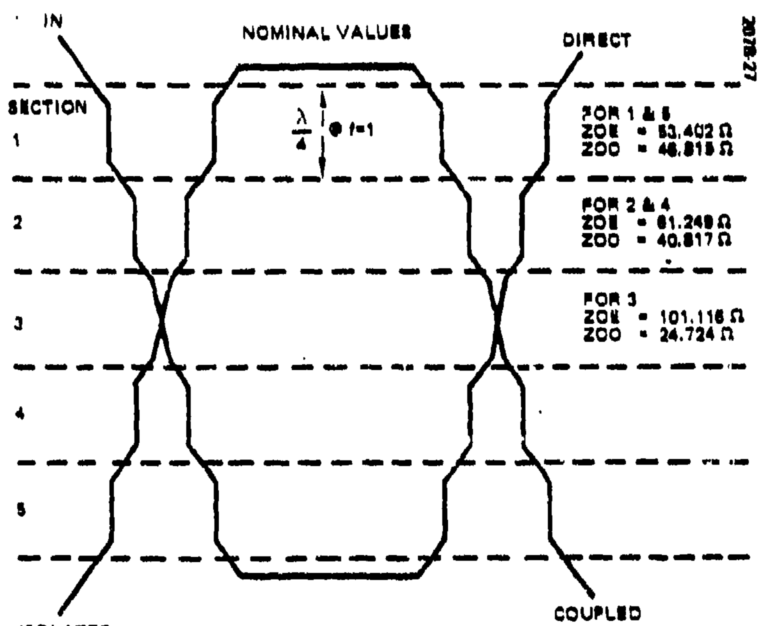


Figure 24. Tandem 3 dB Coupler Schematic

The same center board and outer board thicknesses used in the test circuit are assumed for the five section coupler. The center section of the five section coupler then has an overlap ratio of about 0.66, but the other sections do not overlap. If the center section were completely overlapped, the even mode impedance would be 10 percent higher. If the other sections were in the same plane (edge coupled) with the same horizontal spacing, their even mode impedances would be 1.5 percent and 1.0 percent higher. These impedances were determined from equations by S. B. Cohn[32, 35]. Cohn's equations could be rearranged to determine the impedance of each section from its physical dimensions.

A change of a parameter, such as a reduction in line width, was then applied to the broadside overlapped and edge coupled sections and new even and odd mode impedances computed. The new impedances were then adjusted for the percentage differences between the three layer construction and the model. The new impedances were used to compute the response of the coupler. Table 3 shows a summary of the computed response characteristics for changes in various parameters.

The response of the baseline (five-section) coupler, with the center frequency normalized to 1, is shown in Figure 25. Note that this coupler has a uniform ripple response across the pass band and an almost perfect phase, isolation and VSWR response. Figure 26 shows the computed response when the inner board thickness is reduced by 0.001 inch. Note the increased coupling, reduced isolation and increased VSWR but that the phase difference is still almost a perfect 90 degrees. Figure 27 shows the effect of a 0.001 inch increase in line width, which could be caused by under etching. Note that the coupling is only slightly affected but isolation and VSWR is affected to a greater degree.

A difference in the even and odd mode phase velocities can have a great effect on coupler performance. The phase differences can be caused by the configuration of the circuit, differences in dielectric constant of the circuit boards and also, as discussed in Section VI, by the surface roughness of the copper cladding. Figure 28 shows the response of the coupler with a 0.91 ratio of the even to odd mode phase lengths for the overlapped center coupled case. The phase difference in the more loosely coupled outer sections are

TABLE 3. COMPUTED RESPONSE CHARACTERISTICS

PLOT NO.	COUPLER	COUPLED -dB	DIRECT -dB	ISOLATED -dB	VSWR	PHASE DEGREES
1.	NOMINAL	3.00±0.5	3.00±0.5		1.00	90±0
2.	INNER BOARD -0.001 inch	2.50±0.5	3.70±0.7	23	1.12	90±0
3.	INNER BOARD -0.0005 inch	2.80±0.4	3.40±0.4	38	1.05	90±0
4.	INNER BOARD +0.0005 inch	3.40±0.6	2.70±0.5	36	1.03	90±0
5.	INNER BOARD +0.001 inch	3.80±0.8	2.40±0.6	32	1.06	90±0
6.	OUTER BOARD -0.002 inch	3.15±0.45	2.90±0.5	30	1.06	90±0
7.	OUTER BOARD -0.001 inch	3.05±0.45	2.00±0.4	34	1.04	90±0
8.	OUTER BOARD +0.001 inch	3.05±0.55	3.05±0.55	33	1.05	90±0
9.	OUTER BOARD +0.002 inch	3.00±0.6	3.00±.05	29	1.06	90±0
10.	STRIP WIDTH -0.002 inch	3.05±0.55	3.05±0.55	31	1.06	90±0
11.	STRIP WIDTH -0.001 inch	3.00±0.4	3.00±0.4	33	1.05	90±0
12.	STRIP WIDTH +0.001 inch	3.10±0.6	3.00±0.8	39	1.02	90±0
13.	STRIP WIDTH +0.002 inch	3.20±0.8	3.00±0.8	32	1.03	90±0
14.	ϵ_r -10 PERCENT ODD MODE ONLY	3.70±1.1	3.50±0.7	8	2.1	90±11
15.	ϵ_r +10 PERCENT ODD MODE ONLY	3.50±0.9	3.40±0.7	9	2.1	90±05
16.	ϵ_r -10 PERCENT EVEN MODE ONLY	3.60±1.1	3.50±0.9	8	2.2	90±11
17.	ϵ_r +10 PERCENT EVEN MODE	3.40±0.9	3.40±0.7	9	2.1	90±09
18.	REHNMARK 91 PERCENT EVEN/ ODD MODE PHASE LENGTH	3.20±0.6	3.30±0.6	11	1.75	90±07
19.	(18) WITH 0.7 LINE BETWEEN COUPLERS	3.30±0.7	3.30±0.7	11	1.72	90±05

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adjusted according to the measurement made by Rehnmark[1]. The two middle sections have an even to odd mode phase length ratio of 0.971 and the outer sections a ratio of 0.986. These results are of great significance because they look very similar to the measured response of many coup‿r circuits. Note that the isolation decreases and the VSWR increases as a function of frequency. Note also that the phase deviates considerably from 90 degrees. A summary of the computed results is given in Table 3.

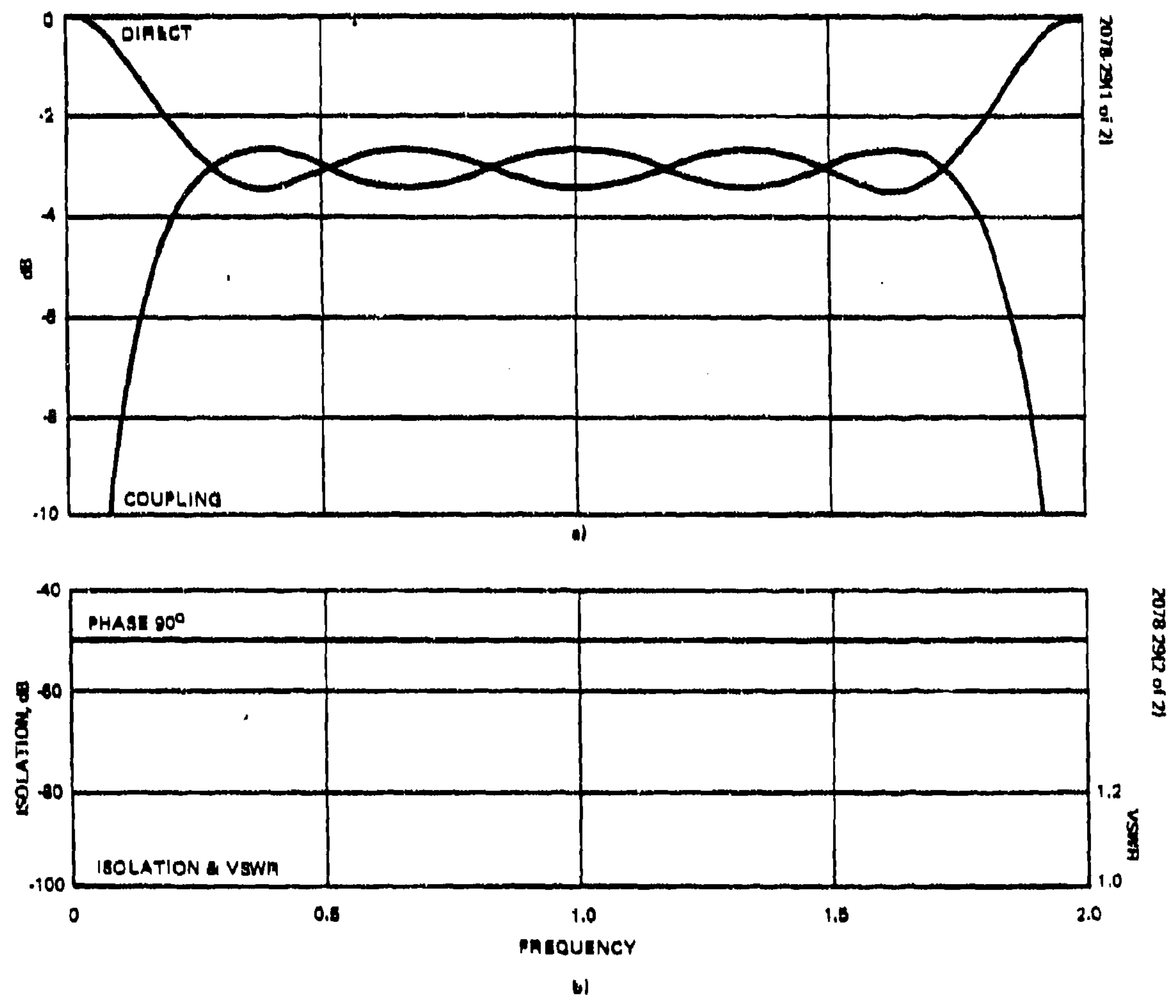


Figure 25. Response of Baseline Coupler

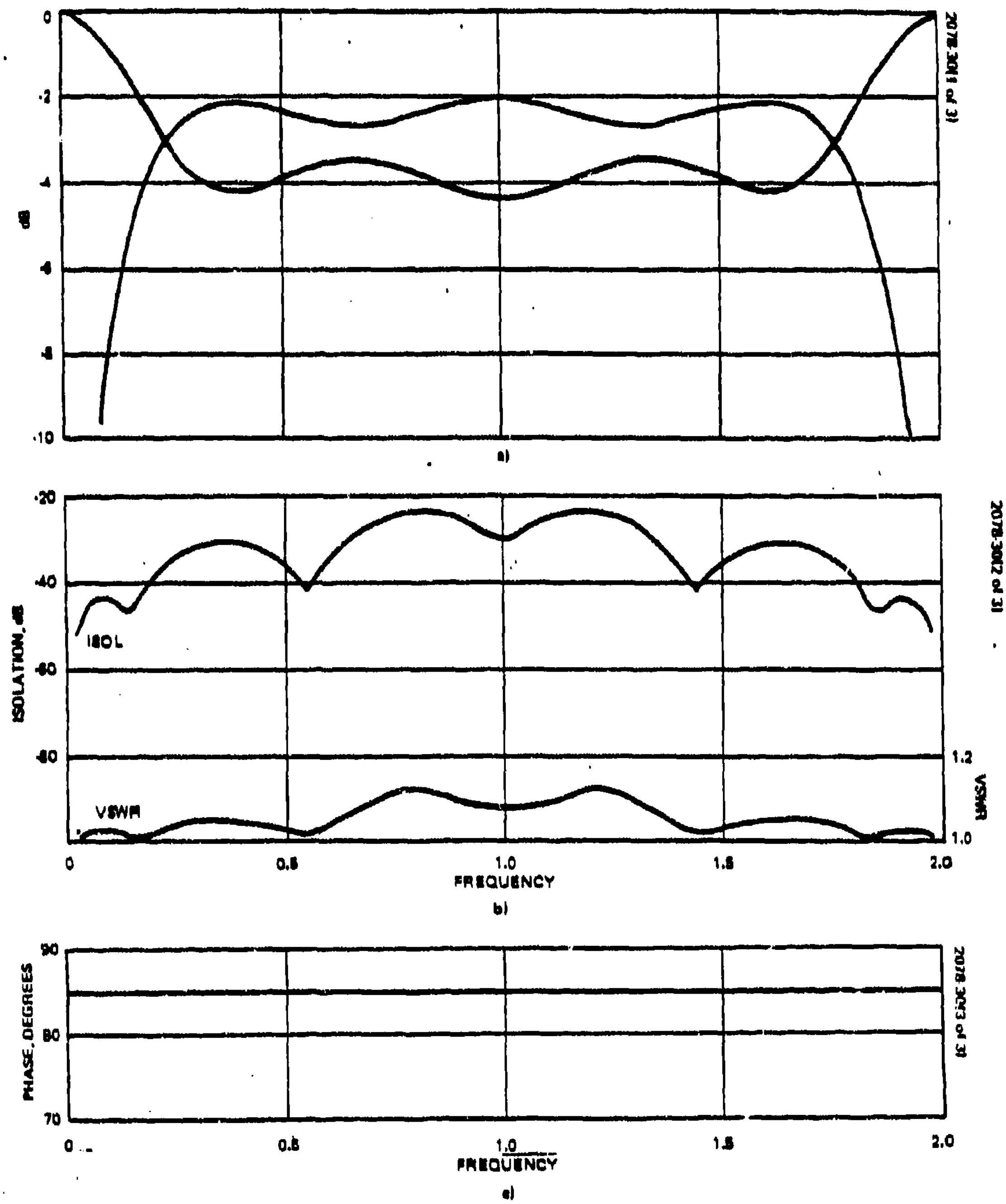


Figure 26. Response with Center Board Reduced 0.001 inch

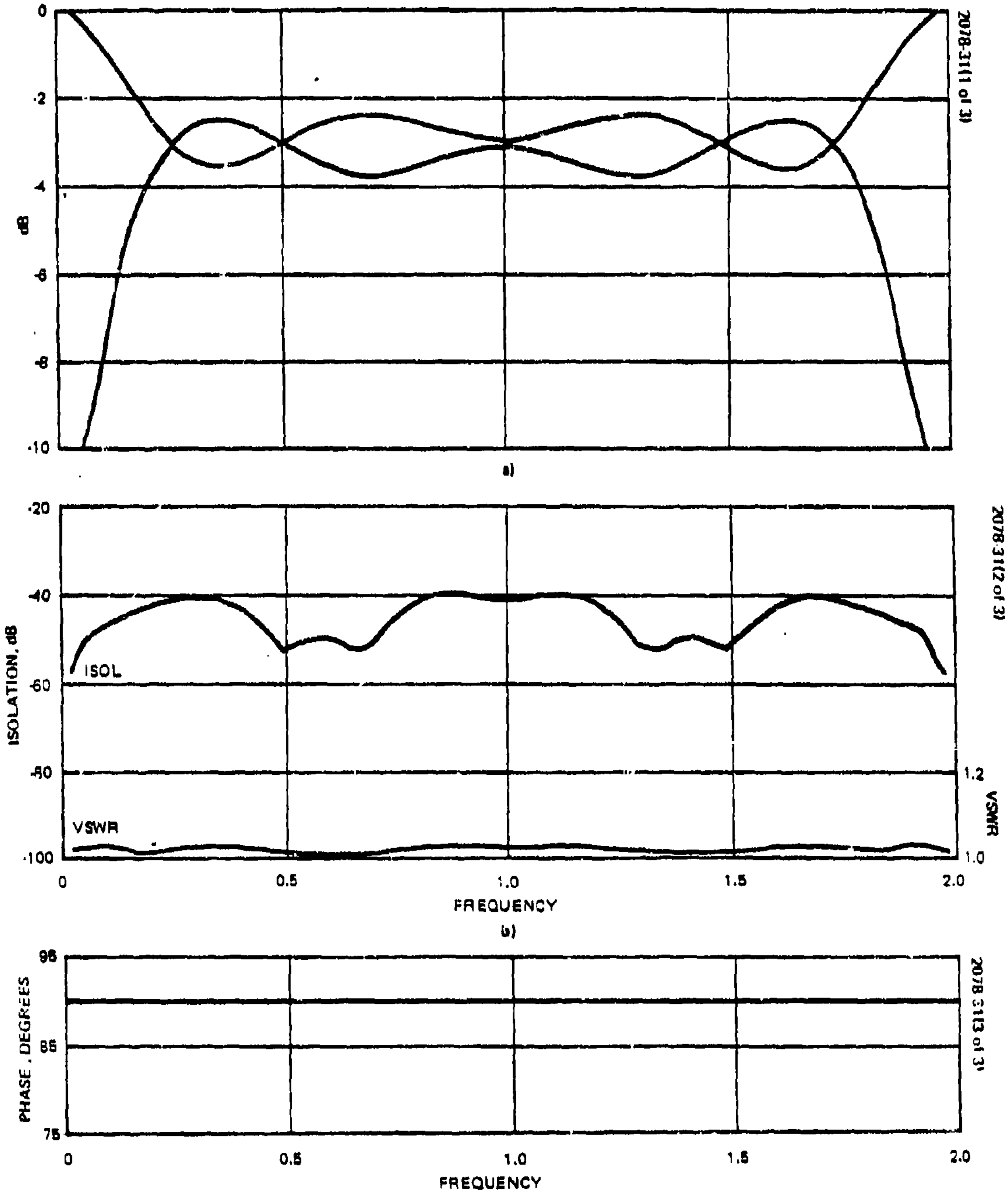


Figure 27. Response with Linewidth Increased 0.001 inch

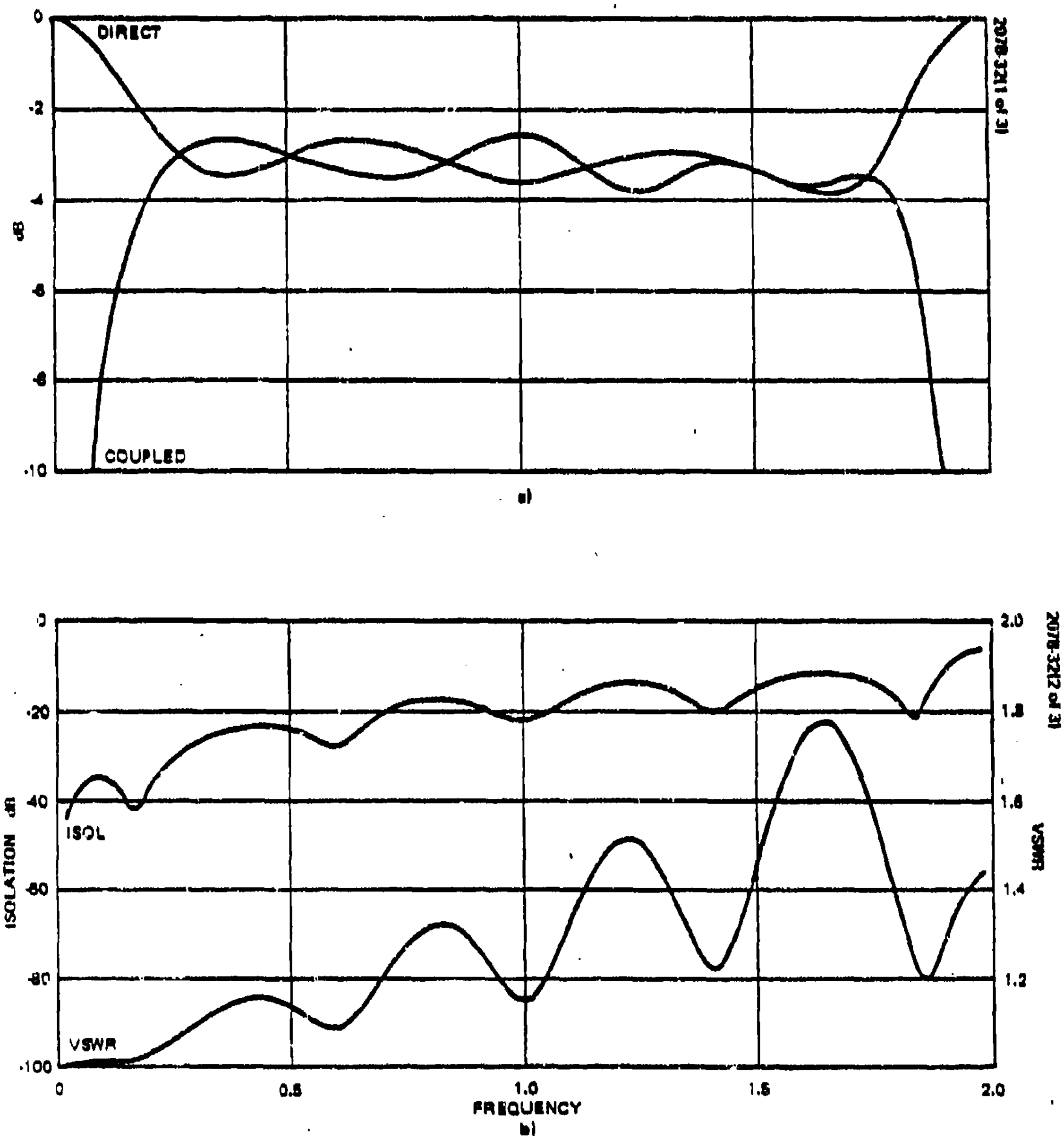


Figure 28. Response with Rehnmark 91 Percent Even/Odd Mode Phase Length

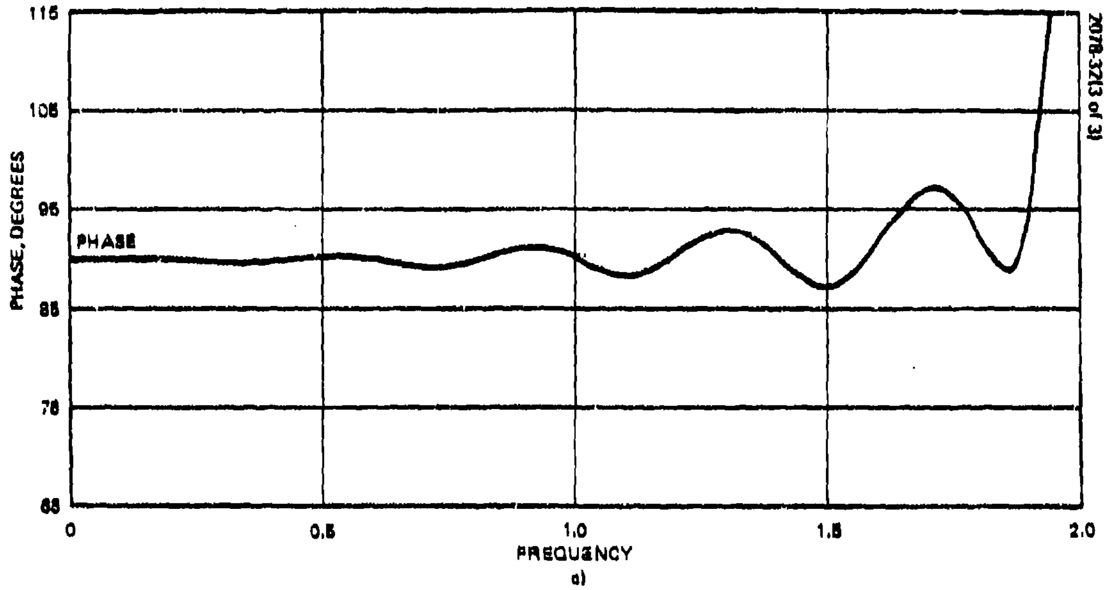


Figure 28 (Concluded).

EXPERIMENTAL DETERMINATION OF THE EFFECTS OF TOLERANCES

Test Circuit

The test circuit selected for the experimental tolerance study is a 3 dB tandem, quadrature coupler. The circuit was designed to use Duroid 5880 and operate from 2 to 18 GHz. Figure 29 is a composite and shows the stripline that is etched on each side of the center board. The nine quarter-wavelength sections and ministrip transitions are clearly visible.

Etched circuit boards, outer boards and test fixture are shown in Figure 30. The connectors are SMA type and have small tabs that connect the center conductor to the stripline by means of the pressure supplied to the outer boards by two aluminum plates and eight screws. The fixture also has two dowel pins that assure accurate alignment between all the parts. The outer shell of each connector is attached to the aluminum plates by four screws.

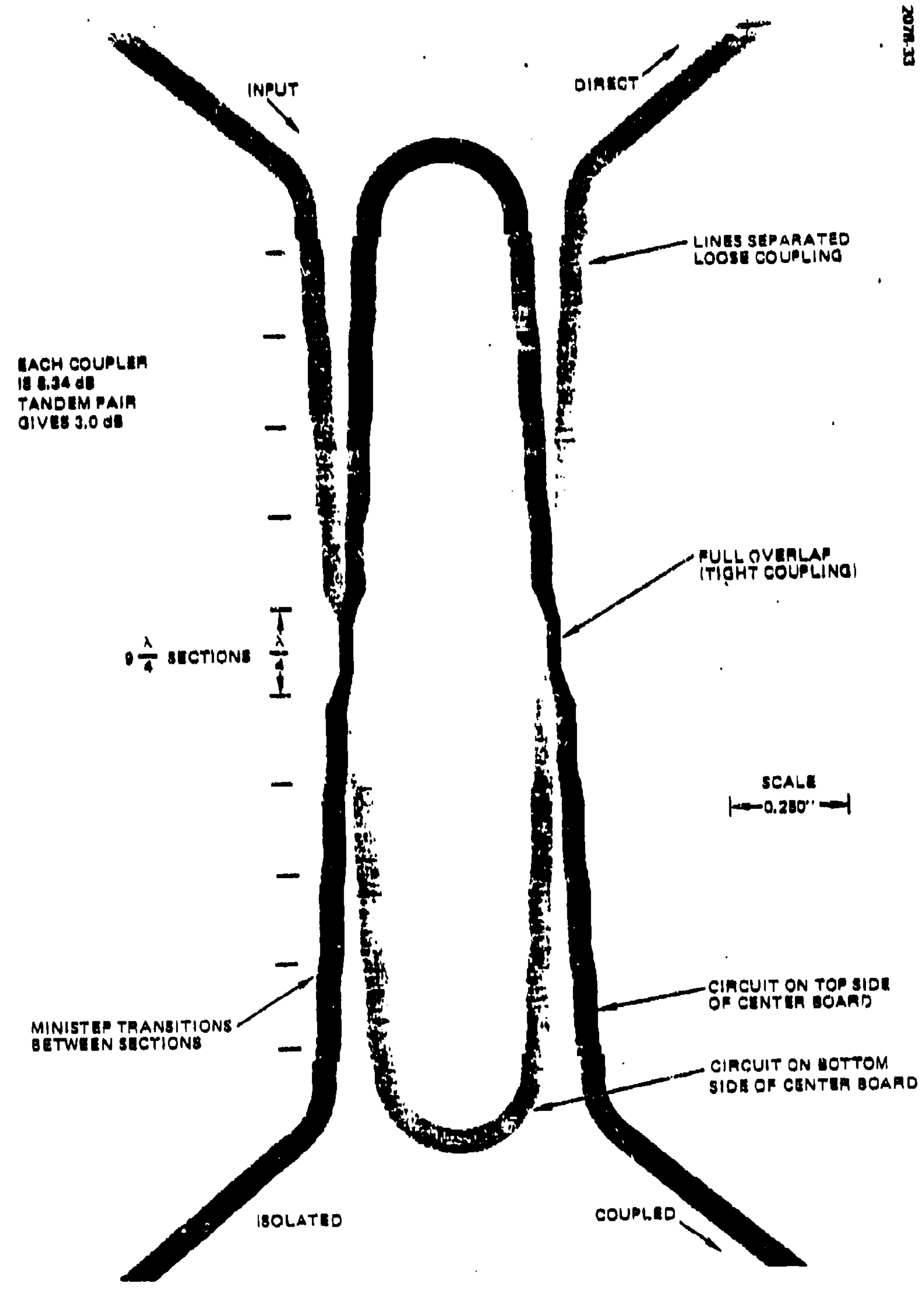
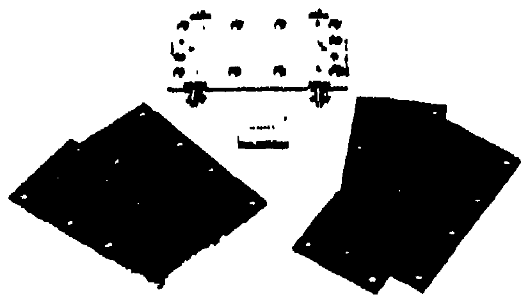
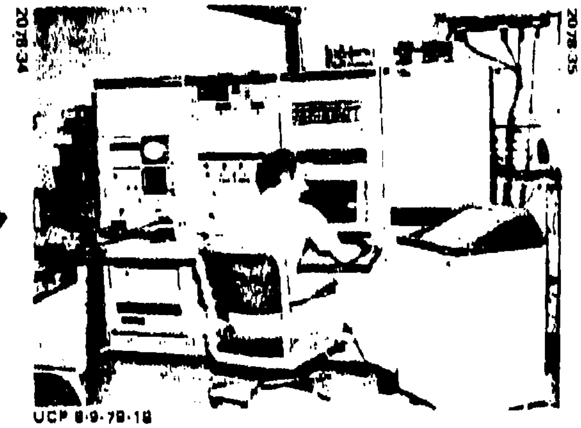


Figure 29. Stripline Composite



UCP 11-18-81-21

Figure 30. Test Fixture and Circuits



UCP 8-9-78-18

Figure 31. Computer Controlled Automatic Network Analyzer

Test Data

Data on the test circuits were taken with the Hewlett Packard computer controlled automatic network analyzer shown in Figure 31. Two sets of test data, with inputs on opposite corners, were taken for each circuit test to assure that symmetry was obtained and connections were properly made. The test data taken at one input are shown in Figure 32. The plotted data include isolation, VSWR, loss (or coupling), the difference in coupling, the output phase compared to a 24.85 cm length of line and the difference in phase of the outputs. The data are in the form of plots for easy visual inspection and in tables when more accurate values may be desired.

Twenty-seven different combinations of inner and outer boards were tested on the automatic network analyzer. Five combinations were also tested a second time. These results always closely matched the original tests.

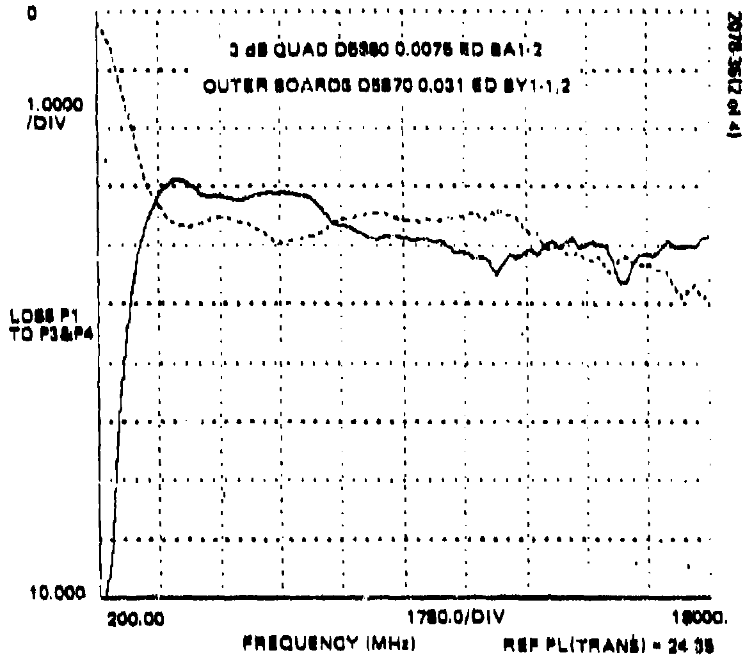
Twenty-three tests were made on circuits that were etched on the inner board and nine tests were made on circuits that were etched on the outer boards. The tests with the circuits etched on the inner board were made from combinations of ten inner boards and four pairs of outer boards. The test with the circuits etched on the outer boards were made from combinations of three inner boards and five pairs of outer boards. There were also six tests of bonded plated assemblies and six tests with the circuits on the center board offset.

D. KREINHEDER NOV. 9, 1981

3DB QUAD D5880 .0075 ED 3A1-2
OUTER BOARDS D5870 .031 ED 3Y1-1.2

FREQ MHZ	ISOL-DB P1 TO P2	VSWR P1	LOSS-DB P1 TO P3	LOSS-DB P1 TO P4	PHASE P1 TO P3	PHASE P1 TO P4
200.000	49.20	1.05	18.25	.20	86.81	-3.22
400.000	40.51	1.03	12.53	.37	83.90	-6.10
600.000	37.97	1.01	9.33	.64	81.37	-8.42
800.000	38.12	1.05	7.37	1.04	78.88	-10.70
1000.000	35.14	1.04	5.81	1.49	77.20	-11.96
1200.000	31.78	1.04	4.04	1.95	75.93	-13.41
1400.000	30.70	1.06	4.17	2.43	74.86	-14.59
1600.000	38.52	1.07	3.70	2.87	74.07	-15.49
1800.000	37.83	1.04	3.40	3.16	73.41	-16.23
2000.000	40.46	1.02	3.14	3.34	72.87	-16.59
2200.000	42.92	1.08	2.99	3.52	72.27	-16.87
2400.000	44.81	1.05	2.89	3.60	71.70	-17.30
2600.000	41.00	1.03	2.89	3.66	71.37	-17.79
2800.000	32.10	1.09	2.93	3.70	70.42	-18.64
3000.000	27.73	1.11	2.99	3.67	69.92	-19.29
3200.000	[illegible]	1.17	3.14	3.64	68.90	-20.32
3400.000	25.37	1.23	3.18	[illegible]	67.90	-21.03
3600.000	26.30	1.14	3.18	[illegible]	67.35	-21.49
3800.000	28.36	1.04	3.18	3.82	66.23	-22.69
4000.000	28.88	1.07	3.19	3.84	65.11	-23.66
4200.000	33.37	1.05	3.22	3.59	64.09	-25.09
4400.000	34.94	1.04	3.23	3.61	62.78	-26.46
4600.000	32.56	1.11	3.19	3.63	61.61	-27.17
4800.000	29.36	1.12	3.13	3.73	60.45	-28.01
5000.000	27.40	1.14	3.12	3.79	59.44	-28.86
5200.000	27.21	1.15	3.11	3.83	59.01	-29.60
5400.000	28.79	1.16	3.11	3.90	58.27	-30.72
5600.000	32.19	1.11	3.10	3.97	57.29	-31.66
5800.000	33.71	1.15	3.12	3.92	56.38	-32.38
6000.000	32.40	1.17	3.14	3.92	55.14	-33.26
6200.000	32.96	1.13	3.18	3.87	54.47	-33.84
6400.000	34.58	1.05	3.21	3.84	53.58	-34.72
6600.000	30.62	1.07	3.28	3.84	52.36	-35.90
6800.000	26.81	1.13	3.41	3.76	51.57	-36.92
7000.000	24.91	1.10	3.50	3.66	50.42	-37.96
7200.000	24.95	1.20	3.67	3.61	49.28	-39.20
7400.000	26.64	1.19	3.66	3.56	48.74	-39.89
7600.000	29.74	1.15	3.71	3.54	47.53	-40.88
7800.000	32.72	1.16	3.79	3.52	46.11	-42.00
8000.000	33.38	1.17	3.83	3.47	45.31	-43.25
8200.000	34.11	1.13	3.91	3.45	44.13	-44.84
8400.000	38.71	1.10	3.89	3.45	42.51	-45.70
8600.000	41.60	1.17	3.85	3.46	41.69	-47.61
8800.000	33.69	1.15	3.87	3.52	40.67	-47.80
9000.000	30.67	1.12	3.85	3.56	39.45	-48.79
9200.000	28.38	1.17	3.80	3.59	38.67	-49.85
9400.000	30.62	1.16	3.73	3.70	37.64	-51.17
9600.000	28.59	1.19	3.89	3.60	36.22	-51.94
9800.000	26.50	1.20	3.91	3.57	35.45	-52.40
10000.00	27.06	1.16	3.98	3.57	34.80	-53.43
10200.00	29.37	1.10	3.93	3.50	33.57	-54.07
10400.00	28.70	1.21	4.03	3.58	32.65	-56.06
10600.00	24.91	1.23	4.14	3.52	31.71	-57.53
10800.00	23.33	1.17	4.11	3.52	30.17	-58.46
11000.00	24.10	1.18	4.12	3.46	28.81	-59.15
11200.00	24.73	1.19	4.25	3.44	27.89	-60.01
11400.00	21.93	1.18	4.20	3.50	26.61	-61.07
11600.00	19.57	1.21	4.29	3.52	24.90	-62.16
11800.00	19.33	1.26	4.32	3.40	24.00	-64.80
12000.00	21.60	1.15	4.31	3.45	23.62	-65.67
12200.00	25.59	1.18	4.16	3.49	21.74	-66.39
12400.00	24.26	1.15	4.23	3.53	20.41	-67.99
12600.00	21.30	1.18	4.13	3.74	19.37	-69.38
12800.00	21.50	1.15	4.08	3.81	17.74	-69.99
13000.00	21.96	1.15	4.19	3.79	16.83	-71.91
13200.00	20.48	1.23	4.02	4.02	15.55	-73.16
13400.00	18.99	1.26	3.92	4.00	13.95	-72.63
13600.00	19.31	1.16	4.06	3.99	13.20	-73.80
13800.00	23.07	1.19	3.90	4.14	12.91	-75.77
14000.00	23.81	1.18	3.87	4.18	11.50	-76.22
14200.00	21.14	1.12	4.06	4.13	10.34	-78.05
14400.00	20.15	1.23	4.01	4.25	9.61	-79.42
14600.00	22.50	1.24	3.94	4.27	8.08	-79.19
14800.00	25.04	1.31	4.00	4.19	7.34	-80.94
15000.00	19.46	1.25	4.04	4.43	5.64	-82.60
15200.00	16.28	1.34	4.29	4.50	4.01	-81.95
15400.00	15.49	1.30	4.64	4.23	3.60	-82.70
15600.00	16.75	1.38	4.52	4.17	4.04	-84.71
15800.00	30.36	1.39	4.31	4.33	4.74	-85.92
16000.00	26.11	1.20	4.16	4.25	2.05	-86.19
16200.00	26.56	1.18	4.14	4.31	1.19	-88.07
16400.00	26.27	1.27	4.20	4.42	.09	-89.39
16600.00	31.87	1.14	4.05	4.42	-1.45	-90.33
16800.00	31.21	1.09	3.92	4.47	-2.81	-91.54
17000.00	23.77	1.24	4.02	4.60	-4.36	-92.57
17200.00	19.66	1.24	4.03	4.59	-4.63	-92.92
17400.00	18.88	1.25	4.02	4.76	-5.03	-93.24
17600.00	20.18	1.31	4.02	4.67	-5.40	-94.80
17800.00	33.65	1.29	3.87	4.91	-6.15	-96.07
18000.00	23.53	1.27	3.86	4.06	-7.66	-95.10

Figure 32. Test Data



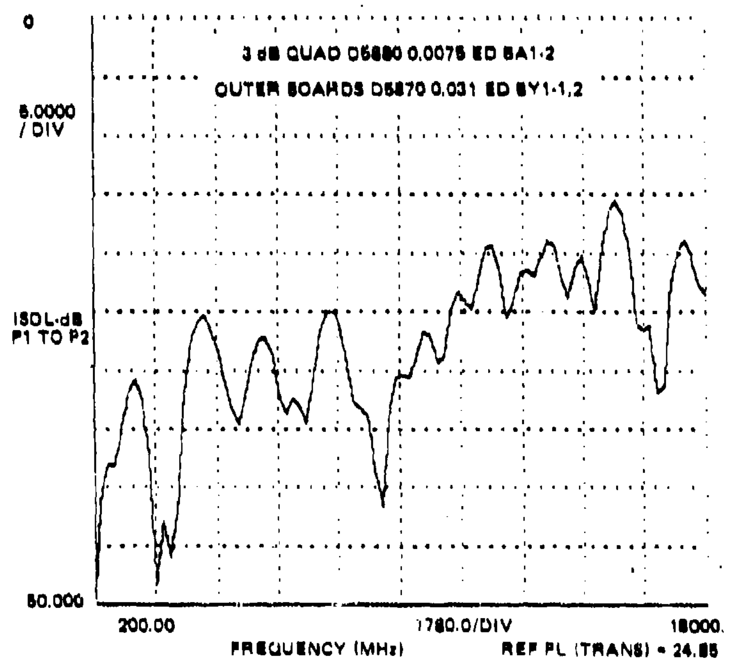
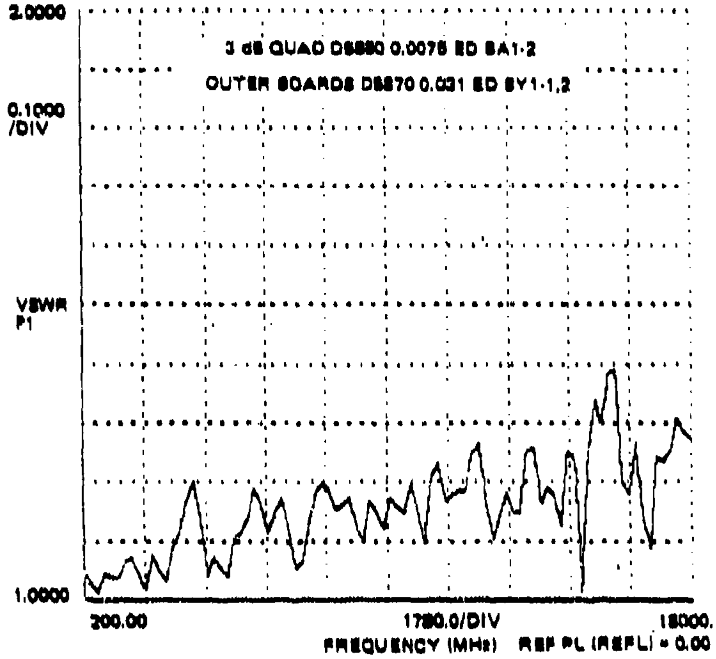


Figure 32. (Continued)



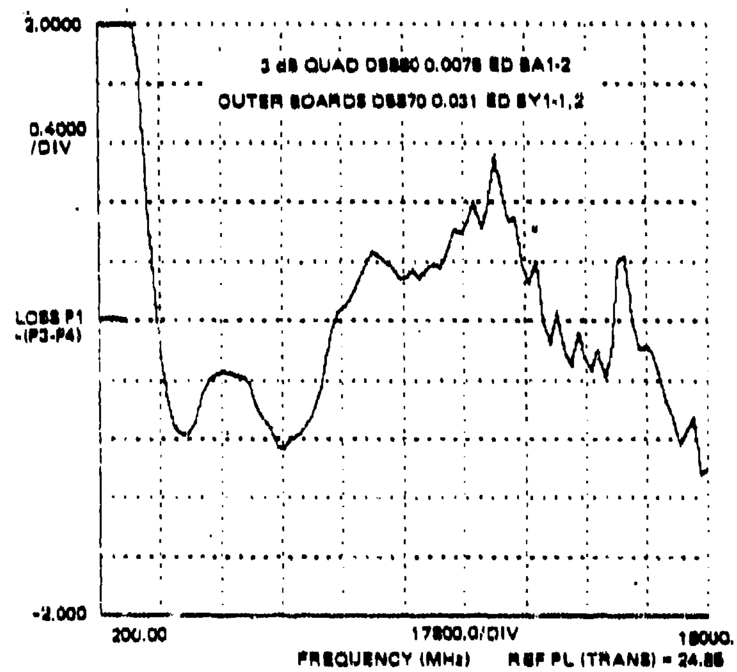
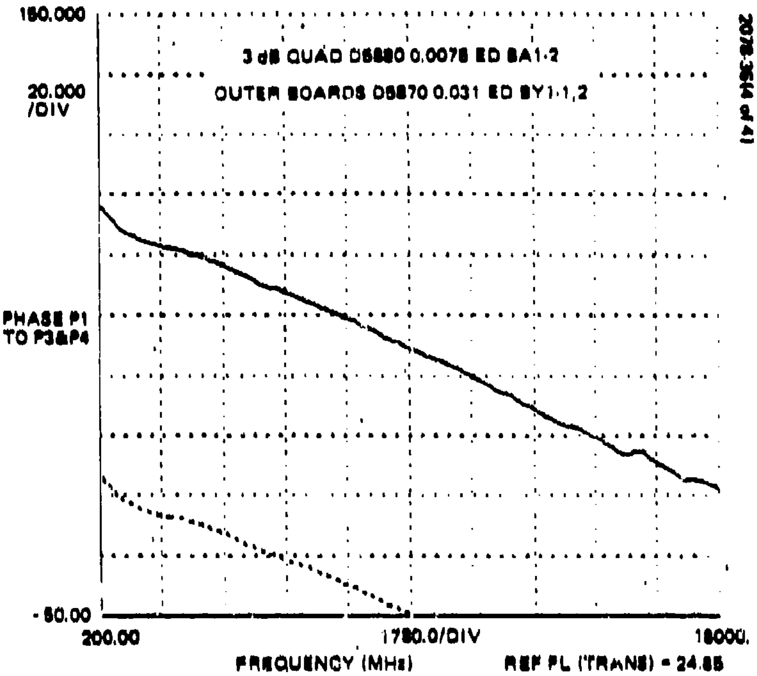


Figure 32. (Continued)



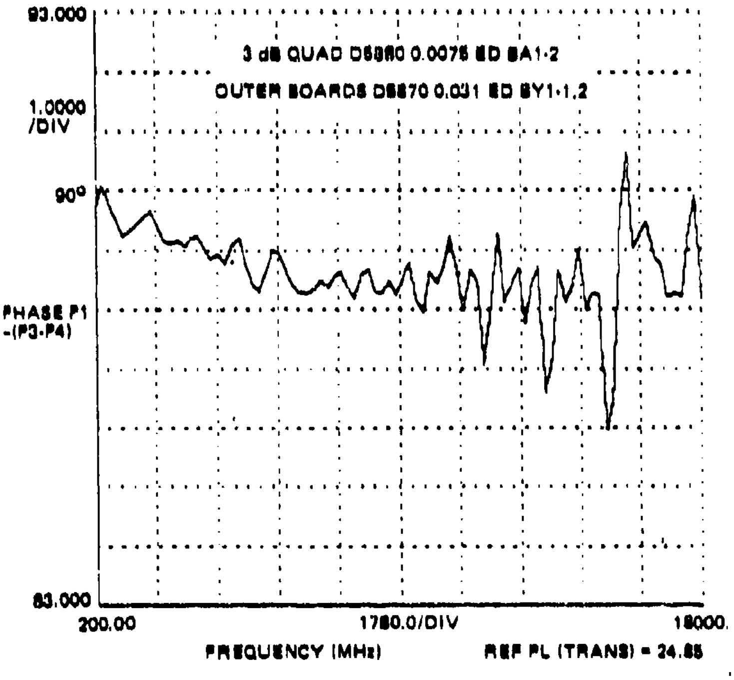


Figure 32. (Concluded)

Three different substrate materials were used for the inner and outer boards. They were Duroid 5880 ($\epsilon_r = 2.20$), Duroid 5870 ($\epsilon_r = 2.33$) and CuClad 217 ($\epsilon_r = 2.17$). Substrate material was obtained with both rolled and electrodeposited copper cladding. Most of the copper foil was 1 ounce although a few boards had 1/2 ounce or 2 ounce copper. The nominal inner board thickness was 0.0075 inch and the outer board was 0.031 inch.

The great quantity of data taken during the tests made comparisons very time consuming. An examination of the data, however, showed that the effects of tolerance variations could be divided into three frequency subbands, 2 to 7 GHz, 7 to 13 GHz and 13 to 18 GHz. A preliminary comparison and sort could thus be made by comparing the average performance in the subband. After this preliminary sort was made, a more detailed comparison could be made using the full frequency band data.

The overpowering amount of data provided by the automatic network analyzer, and the large number of interacting variables made it difficult to arrange the data in an orderly manner. The summary of test results is then presented in discussion format rather than in tables or curves.

SUMMARY OF TEST RESULTS

Circuits Etched on Inner Board, Effect of Changing Inner Board

These are the performance changes that were noted when different inner board circuits were tested with the same outer boards.

Thickness

A 0.0005 inch reduction in the thickness of the inner board causes an increase in coupling of about 0.6 dB.

Dielectric Constant

Three materials were used with different dielectric constants: CuClad 217 $\epsilon_r = 2.17$, D5880, $\epsilon_r = 2.20$, and D5870 $\epsilon_r = 2.33$. The test data showed that the coupling was almost unaffected by changes in the dielectric constant. The higher dielectric constant of the D5870 should cause an increase in coupling but it is negligible compared to the variations caused by the slightly different thickness between the materials. The isolation of

couplers made with D5870 center boards was about 2 dB poorer than couplers with the other materials, especially at the lower frequencies. This indicates a change in the impedance match. The difference in dielectric constant can also be seen in the phase characteristics.

Rolled versus Electrodeposited Copper

Rolled copper increases coupling about 0.2 dB at low frequencies, 0.5 dB at board center and 0.4 dB at the higher frequencies. Rolled copper reduces isolation about 1 dB and, from phase data, shows a lower effective dielectric constant.

Compression of Circuit into Dielectric Material

A 0.9 dB difference in coupling primarily at the center of the frequency band was noted between two Duroid 5880 circuits that came from the same sheet of material. Both boards were tested a second time with the same results. An examination of the boards showed that the center sections of one coupler had been pressed about 0.0004 inch into the dielectric material. This was probably the result of leaving one circuit in the test fixture, with the screws tightened, for an extended period of time so that the material cold flowed. The center of the coupler has fully overlapped sections so there is a double thickness of copper cladding and this small area thus bears the greatest load.

Direction of Glass Weave

The CuClad 217 has a glass cloth laminate. Test circuits that were etched on the material in line with the weave and at 45 degrees to the weave showed no significant differences in performance.

Change of Strip Width

The greatest difference in strip width between any two circuits was 0.002 inch. No correlation between strip width and coupler could be identified with the samples tested. Based on the analytical model the greatest variation in coupling would be 0.2 dB. Since the coupling also varies with frequency the small coupling change could easily be masked by other parameters.

Circuits Etched on Inner Boards, Effect of Changing Outer Boards

These are the performance changes that were observed when different sets of outer boards were tested with the same inner board.

Thickness

A 0.005 inch increase in the thickness of each board (0.010 inch overall) causes a 0.2 dB increase in coupling at the lower frequencies. There is almost no change in coupling at midboard and the higher frequencies.

Dielectric Constant

The performance of circuits with outer boards made from Duroid D5880 (dielectric constant 2.20) and CuClad 217 (dielectric constant 2.17) were compared to circuits made from Duroid D5870 (dielectric constant 2.33). On the average, the higher dielectric constant of the D5870 reduced coupling 0.2 dB at the lower frequencies, 0.5 dB at the middle frequencies and 0.3 dB at the higher frequencies for boards with approximately the same thickness. The high dielectric outer boards also had about a 2.0 dB overall improvement in isolation and a lower VSWR.

In one set of tests the same inner board was used with a pair of D5880 outer boards (thickness 0.0259 inch) and a pair of the higher dielectric constant D5870 outer boards (thickness = 0.0314 inch). The coupler with D5870 outer boards had 3 dB better isolation, lower VSWR, but almost exactly the same coupling as with the D5880 outer boards. The reason for this improvement is because of the more equal phase velocity between the even and odd modes. The more equal phase velocity also shows up as reduced ripple in the phase response. The higher dielectric constant of the outer board compensates for the increase in effective dielectric constant caused by rough electrodeposited copper on the center board. The increased thickness of the D5780 outer board partly compensated for increased even mode impedance caused by the higher dielectric constant and thus there is little change in coupling.

Offset Circuits

Six center boards were etched with the circuits on opposite sides of the boards offset rather than being perfectly aligned. Circuit alignments are typically held to less than ± 0.001 inch. These boards had offsets of 0.003,

and 0.006 inch, in two directions, to have an increase considerably above the ± 0.001 tolerance.

These circuits were tested. No significant difference in performance was found that could be related to the offsets.

Circuits Etched on Outer Boards

Nine couplers were made with the circuits etched on the outer boards, instead of on the inner boards. These couplers were made from combinations of five pairs of outer boards and three inner boards. The inner board had no copper. In these couplers the smooth outer copper surfaces face each other through the thin center board. Alignment between the circuits was achieved by the use of dowel pins.

General Observations

The couplers with outer board circuits are, on the average, 0.8 dB overcoupled at low frequencies, 0.8 dB undercoupled at middle frequencies and 0.5 dB overcoupled at high frequencies.

The circuits with the D5880 material for both the center boards and outer boards and rolled copper on the outer boards had a uniform coupling response across the frequency band. Circuits with electrodeposited copper on the outer boards had much greater variation incoupling across the band. Circuits with CuClad 217 center boards, regardless of the type of outer board, also had a greater variation across the frequency band.

The differences between the responses of electrodeposited copper and rolled copper on the outer boards was unexpected. It had been assumed that the electrodeposited copper surface roughness would have a strong effect on the center board, but not on the outer board.

Inner Board Thickness

From the tests that were run, the relationship between inner board thickness and coupling cannot be easily determined. For example, a circuit made with D5880, which had an average thickness of 0.0073 inch, had about 0.2 dB greater coupling at low and middle frequencies than a circuit mode with D5880 which had an average thickness of 0.0078 inch.

In another example, a circuit made with CuClad 217 which had an almost constant thickness of 0.0072 inch, had about 0.6 dB greater coupling overall than a circuit made with D5880 which had an average thickness of 0.0073 inch.

This inconsistency may result, at least partially, because of the following: Visual inspection the CuClad 217 board showed a greater depth of impression from the circuit than the 0.0073 inch thick D5880 board. This D5880 board had an overall variation in thickness of 0.0004 inch which could be a cause for the actual spacing between the most tightly coupled section to be significantly different from the average board thickness.

Outer Board Thickness

Three different sets of outer boards were used. They were made of D5880 with rolled copper (dielectric thickness = 0.0307 inch), D5880 with electrodeposited copper (dielectric thickness = 0.0310 inch) and CuClad 217 with electrodeposited copper (dielectric thickness = 0.0309 inch). The range of thickness variation is 0.0003 inch, which would have an insignificant effect on the couplers' performance.

Rolled versus Electrodeposited Copper

The coupling of all the circuits with rolled copper were within 0.3 dB of each other over the band and the coupling of all the circuits with electrodeposited copper were also within 0.3 dB of each other over the band. On the average, the circuits with rolled copper had 0.1 dB less coupling at low frequencies, 0.8 dB greater coupling at center frequencies and 0.3 dB greater coupling at high frequencies. The isolation, VSWR and phase ripple for the rolled copper circuits were the same, or slightly better than for the electrodeposited circuits.

COMPARISON OF CIRCUITS ETCHED ON INNER BOARD AND CIRCUITS ETCHED ON OUTER BOARDS

General Observations

In general, the coupling of the inner board circuits showed less variation in the level of coupling over the frequency range, had a greater overall level of coupling, worse isolation and VSWR, and a greater phase ripple than the outer board circuits.

Two Pairs of Similar Inner Board and Outer Board Circuits Compared

One pair of circuits was made from CuClad 217 with electrodeposited copper; the other pair of circuits was made from D5880 with electrodeposited copper. In both cases the thicknesses of the inner and outer boards were the same.

Coupling

On the average, the inner board circuits had 0.1 dB greater coupling at low frequencies, 1.3 dB greater coupling at center frequencies and 0.3 dB greater coupling at high frequencies.

Other Parameters

Isolation was about 1 dB better for the outer board circuits. The VSWR and phase ripple were about the same.

Bonded and Plated Circuits

Six assemblies were fabricated with the outer and inner boards bonded together and then shell plated to make an integral assembly. All inner boards had rolled copper. 3M bonding material number 6700 was used. This material has a nominal thickness of 0.0015 inch and a dielectric constant of 2.35. The bonding material covered the stripline circuit, as is the usual case for printed circuit boards.

The six assemblies were tested. All assemblies had characteristics similar to each other but different from those of the unbonded circuits. Coupling was good at the band edges but was about 1.6 dB undercoupled at the band center. Thus, there was lower coupling on average, with a large decrease in coupling at band center. The isolation and VSWR was also consistently poorer.

The mechanical bonding of the boards was excellent but the electrical performance of the circuits was not adequate. Additional bonding experimentation is required. It may be necessary to cut the bonding material away from the conductor strips. The problem may also be caused by the high bonding pressures between parallel platens. This would tend to impress the circuit into the dielectric material. Another bonding process, such as

autoclave bonding, that provides uniform bonding pressure across the surface may provide better results.

COMMENTS ON THE EFFECT OF KEY PARAMETERS ON THE PERFORMANCE OF 3 dB QUADRATURE COUPLERS

Inner Board Thickness

The thickness of the inner board is very critical. A change in inner board thickness of 0.0005 inch causes an approximately 0.6 dB change in the coupling.

Outer Board Thickness

The thickness of the outer board is not critical. A change in outer board thickness of 0.005 inch causes an 0.2 dB change in coupling.

Dielectric Constant

Surprisingly, the test data indicate that the dielectric constant is not critical. Changes in dielectric constant, as large as 5 percent, made little difference in the coupling although there were naturally large changes in the phase slope. Changes in dielectric constant had only small effects on isolation and VSWR.

Line Widths

The line widths are not critical. Little change in performance was observed for circuits with variations in line widths of 0.002 inch. Control of line widths to within 0.001 inch of nominal should provide adequate performance.

Circuits Alignment

The alignment between the two etched circuits is not critical. No noticeable change in performance was observed for offsets of 0.003 inch and little change was observed for 0.006 inch offset. Alignment to a tolerance of 0.001 inch should be adequate.

Impression of the Circuit Into the Dielectric Material

The impression of the circuit into the dielectric is a critical parameter. It causes the spacing of the circuits to vary, especially in the overlapped center section. This results in changes of performance that are frequency sensitive.

Surface Roughness of Cladding

The surface roughness is a critical parameter. Care must be taken to use relatively smooth surfaces, especially on the inner boards.

Bonding of Circuit Boards

This is a critical process. The bonding caused an impression of the circuit into the dielectric. Large variations of coupling over the frequency band were noted.

SECTION VIII
IMAGING AND ETCHING OF STRIPLINE SUBSTRATES

INTRODUCTION

No other stripline fabrication processes are as important as imaging and etching in transforming the RF stripline engineer's design into a proper functioning circuit. Once the engineer's design is captured on paper, a graphic artist then has the task of converting the circuit design into a working tool for use in fabrication. The graphic artist may choose to use a coordinatograph (Figure 33) to cut rubylith at several times the original drawing and then reduce this copy to a one-to-one mylar film with an accurate reduction camera. This mylar film is called the master pattern. Another method for master pattern fabrication would be to load the circuit trace's dimensional characteristics into a computer-aided design system and photo plot the image directly onto a working mylar film or glass master, using an automatic graphics plotter (Figure 34). Whatever the instrumentation capabilities are, the

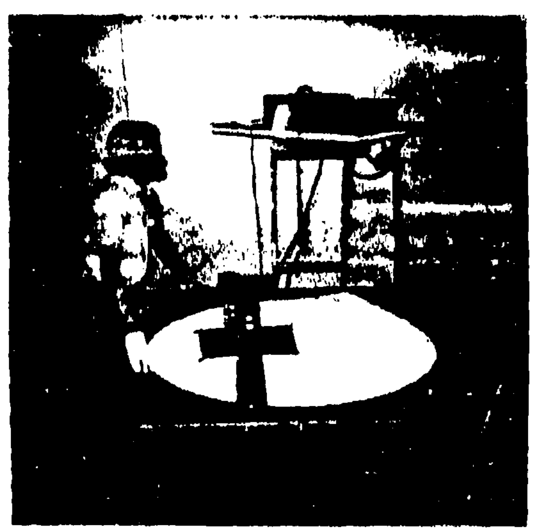


Figure 33. Rubylith Being Cut on Coordinatograph

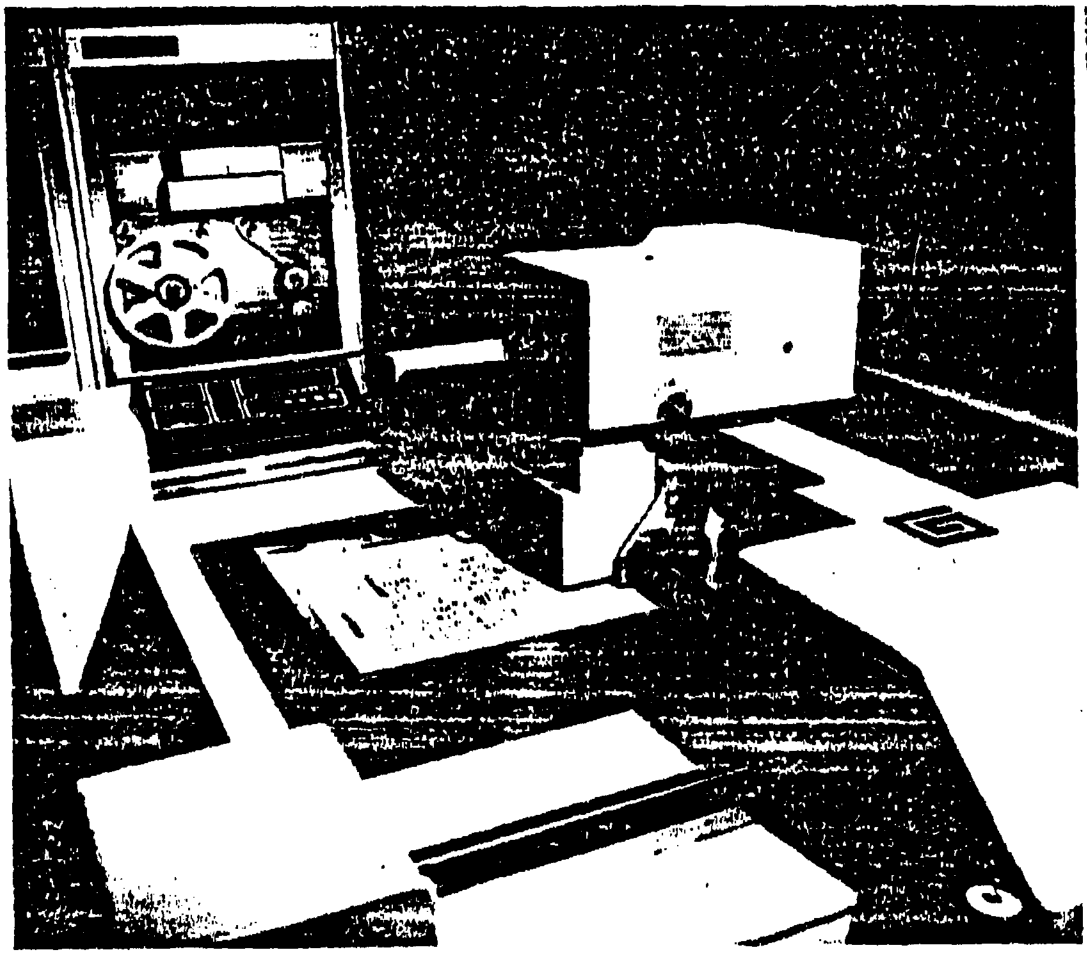


Figure 34. Gerber Plotter.

graphic artist must transform the engineering design into negative and positive master pattern films for use in fabrication. Optimization of the fabrication of master films was not a subject of this report. However, it is important to note that the stripline circuit will not function properly without an exact master film, no matter how good the subsequent fabrication processes are. Figure 35 is a photocopy of a 3 dB hybrid quadrature coupler original master pattern. Figure 36 is an enlarged view, showing the characteristic step function of this coupler. The front and rear circuit traces are identical, differing only in orientation in that the front circuit is a mirror

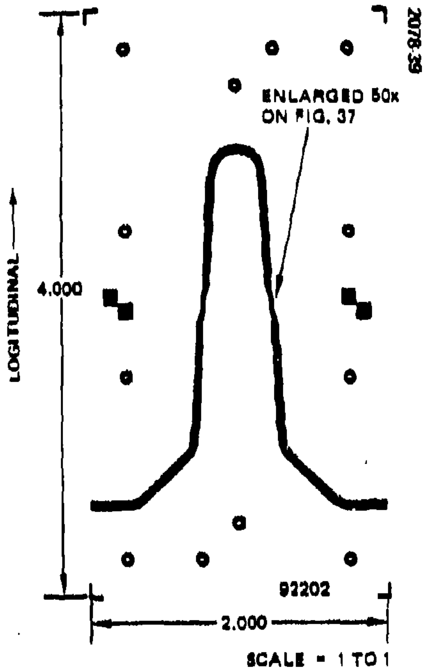


Figure 35. 3 dB Quad Master Pattern

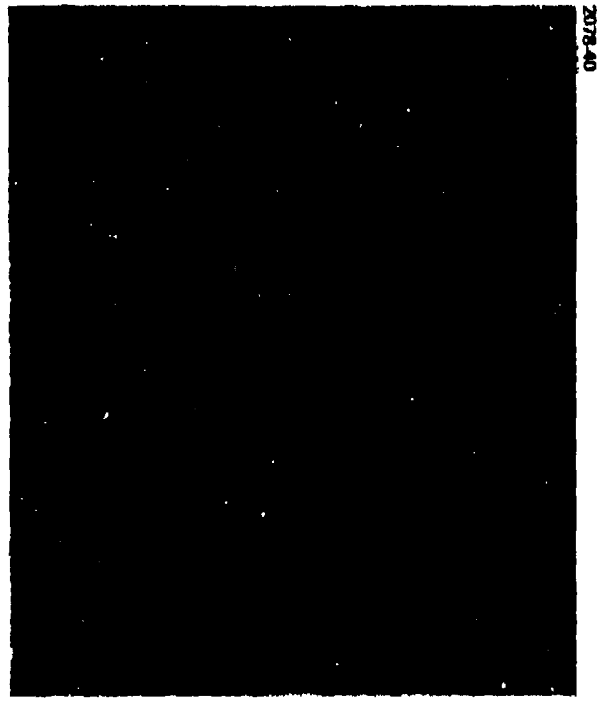


Figure 36. Closeup of 3 dB Quad Showing Step Function (50X)

image of the rear circuit. When placed on top of each other and properly registered, there is an area where both top and bottom circuit traces can be seen to be aligned within 0.0001 inch over one another, as depicted in Figure 37.

IMAGING

Before imaging can be achieved onto a copper clad laminate, the copper surface must be prepared for resist lamination. Resist, resist lamination, exposure and processing are discussed individually in later sections. It is important to mention that without proper copper surface preparations, no matter how optimum the subsequent processes are, the resist lamination would fail because of lack of resist adhesion.

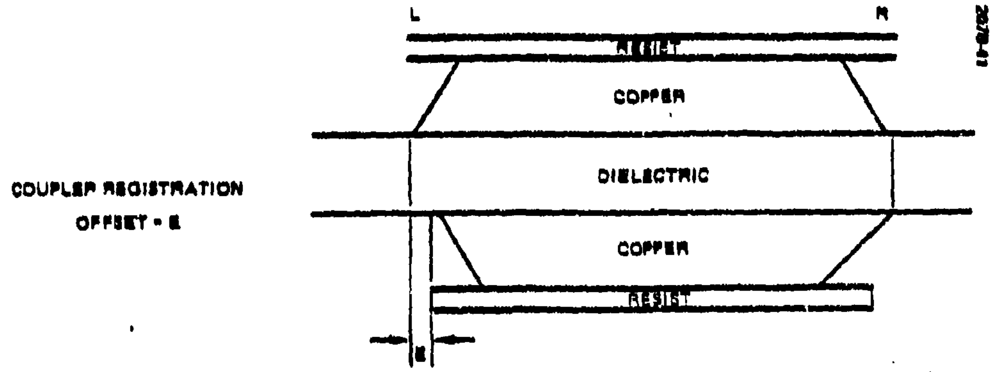


Figure 37. Representation of Coupler Area

Surface Preparation Techniques: Prelamination Clean

Currently two methods are used in this printed wiring board facility for surface preparation of thin laminate material. These are: 1) black oxide treat (short treat); and 2) ammonium persulfate/sulfuric acid, citric acid clean (microetch). The latter was implemented during this project.

Black Oxide Treat (Short Treat)

This procedure is designed to evenly coat a copper clad thin laminate with an oxide coating by rinsing it in a sodium hypochlorite solution. This method is currently being used during fabrication of all our thin laminate innerlayers and has proved successful in providing an adequate surface for maximum resist adhesion. The main drawback is that the process is a very time consuming procedure. A much faster method of copper surface preparation was initiated for the stripline circuits.

Ammonium Persulfate/Sulfuric Acid, Citric Acid Clean (Microetch)

Ammonium persulfate is primarily used in the printed wiring circuit shop as an etchant prior to electroless copper and electrolytic copper deposition. However, its application as a preresist laminate spray clean is not well documented. The ammonium persulfate activity is not very stable during routine spray usage, as can be seen in Figure 38. A method is being developed here to control this process with the use of a chemical feed and bleed system controlled by solution volume and copper concentration.

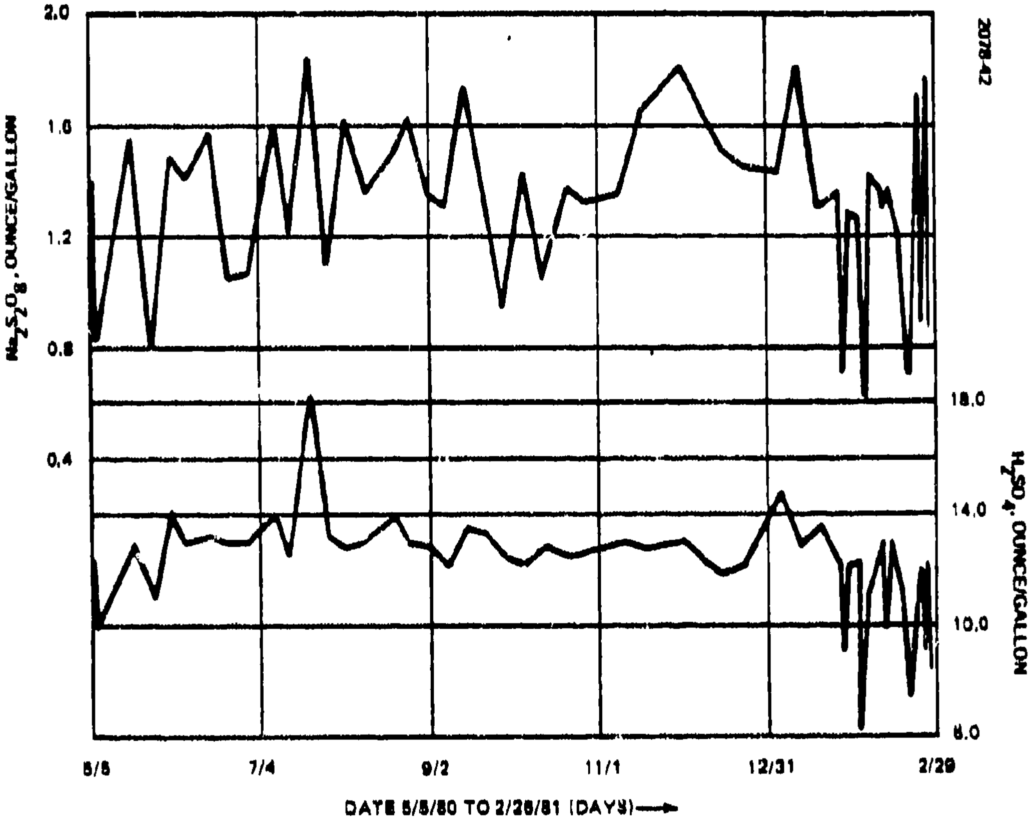


Figure 38. Activity of Ammonium Persulfate Solution During Spray Application

An experiment was conducted to determine the extent of etching with the ammonium persulfate. Three hundred eighty-four 18 X 13 inch panels were run through the spray cleaner during an eight hour shift. The copper concentration was determined to be 0.497 oz/gal after processing. Since the stripline process panel size selected was 8 X 14 inches, it was calculated that 9.07 μin. would be etched off each side. This proved to be an adequate etch for subsequent resist lamination of stripline substrates. See Table 4 for calculations.

To prevent further oxidation of the panels, a 1 minute soak in a citric acid/sulfuric acid rinse was used. This rinse also acts as an adhesion promoter for the resist. The panels were then rinsed in tap water, DI water, and air dried.

TABLE 4. AMMONIUM PERSULFATE ETCH DATA

SQUARE FEET PROCESSED	1192.32
COPPER ETCHED	0.497 oz/gal.
SUMP CAPACITY	20 gal.
TOTAL COPPER ETCHED	9.940 oz. Cu
1 oz. COPPER	0.0014 inch
$\frac{9.94 \text{ oz. Cu } 0.0014 \text{ inch}}{1 \text{ oz. Cu}}$	= 0.0139 inch Cu
$\frac{0.0139 \text{ in. Cu ETCHED}}{1192.32 \text{ ft}^2 \text{ PROCESSED}}$	= 1.167×10^{-5} inch Cu ETCHED/ft^2 PROCESSED
1 PANEL = $(8 \times 14) = \frac{112 \text{ in}^2 \text{ft}^2}{144 \text{ in}^2} = 0.7778 \text{ ft}^2$	
$0.7778 \text{ ft}^2 \times 1.1671 \times 10^{-5}$ in	= 9.0774×10^{-6} in. ETCHED

PHOTO RESIST

In selecting a resist for stripline imaging, liquid film was not selected since the application of the resist to substrate would require high capital investment. Since this facility utilizes dry film for conventional printed wiring board fabrication, dry film was selected for the striplines.

RESIST LAMINATION

Conventional resist laminators designed for use with dry films apply the resist to a substrate under heat and pressure. The heated rollers on the laminator come in contact with the resist and transfer heat directly to the substrate (Figure 39). Hughes,Tucson,does not preheat boards prior to lamination and has found excellent lamination results. Resist lamination parameters for stripline circuits were identical to those used for conventional thin laminate material. These are:

5 $\pm$1/2 ft/min throughput

210 $\pm$5°F

260 $\pm$10 pounds per sq.in. air pressure

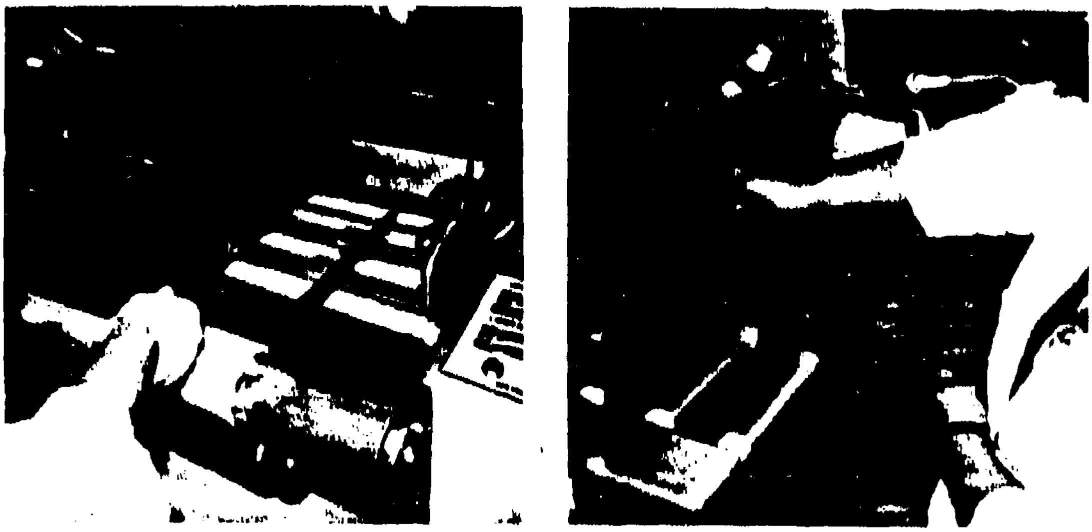


Figure 39. Resist Lamination Process

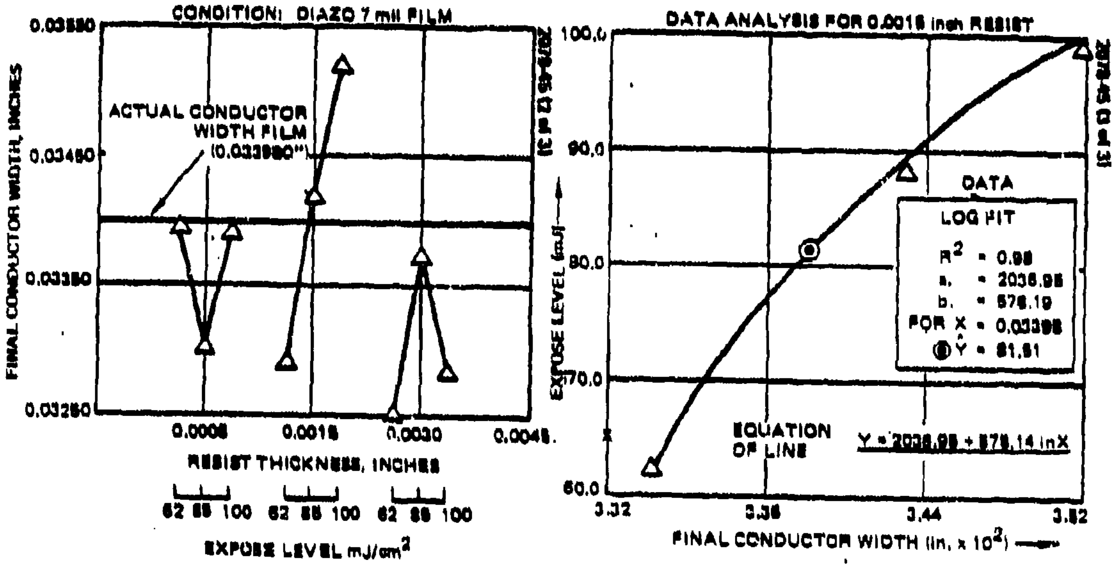
RESIST SELECTION

At the onset of the program, an experiment was conducted to establish a resist thickness to be used. The thicknesses of dry film photoresists available were 0.0006, 0.0015, and 0.0030 inch.

Test panels of 0.006 inch copper clad epoxy glass were prepared for resist lamination,using the microetch technique described earlier. The panels were divided into three groups and each laminated with a different resist thickness.

Panels from each group were then exposed using artwork with a known line width at three different exposure levels. These levels were 62, 85, and 100 mJ/cm^2 (mJ/cm^2 = milliJoules per centimeter squared). For a more detailed description see exposure section. The panels were then processed and etched as though they were conventional printed wiring boards.

Microsectional analysis of each of the panels was then conducted to determine actual reproduced line widths. The 0.0015 inch thickness resist performed the best. The other resist thicknesses did not perform as expected and were abandoned as candidates, as depicted in Figure 40.



RESIST THICKNESS (INCHES)	EXPOSE LEVEL mJ/cm²	CONDUCTOR WIDTH (INCHES) DIAZO FILM
0.0006	62	0.03339
0.0006	85	0.03303
0.0006	100	0.03393
0.0015	62	0.03293
0.0015	85	0.03418
0.0015	100	0.03519
0.0030	62	0.03518
0.0030	85	0.03376
0.0030	100	0.03284

Figure 40. Reproduction of Conductor Width versus Expose Level

PHOTO MASKS

As was stated earlier in this report, the graphic replication techniques of artwork is one of the most important processes in fabricating a functioning RF stripline component. Once a mylar master pattern is received, it must be subjected to a stabilization period for a minimum of 24 hours at 50 ±5 percent relative humidity and 72 ±2°F for geometrical positioning to be dimensionally correct. Glass master patterns have the inherent advantage of being stable to environmental changes and are recommended for use in printed wiring board facilities without adequate environmental controls.

In this study, engineering personnel at Hughes, Canoga Park, provided both mylar and glass master patterns. The glass pattern was received with registration pins already attached and was used directly in production (Figure 41). However, the mylar master pattern was treated as a conventional printed wiring board master pattern to determine if any special handling techniques would be necessary to produce stripline circuits from mylar master patterns, or if the glass master pattern was the only alternative for fabrication.

The following is a description of the task required to produce a production diazo mylar film from a mylar master pattern, using manual methods.

Fabrication Techniques of Mylar Phototool

1) Duplicate master

2) Check duplicate for reproduction of line widths and dimensional tolerance.

3) Register tooling pads of duplicate masters on a drill template. The drill template is described in the machining section (Figure 42).

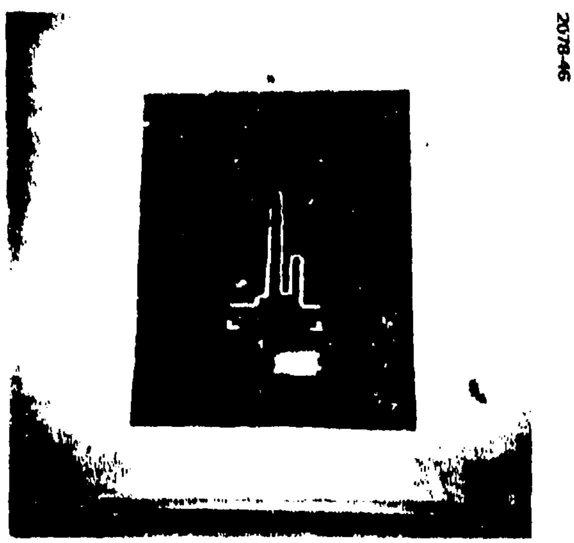


Figure 41. Example of a Glass Master as Received

4) Expose "paste up" on diazo (Figure 43).

5) Develop diazo (Figure 44).

6) Register diazo working film on template (Figure 45).

7) Punch four tooling holes (Figure 46).

8) Touch up film (Figure 47).

Figure 42. Manual Step and Repeat Process

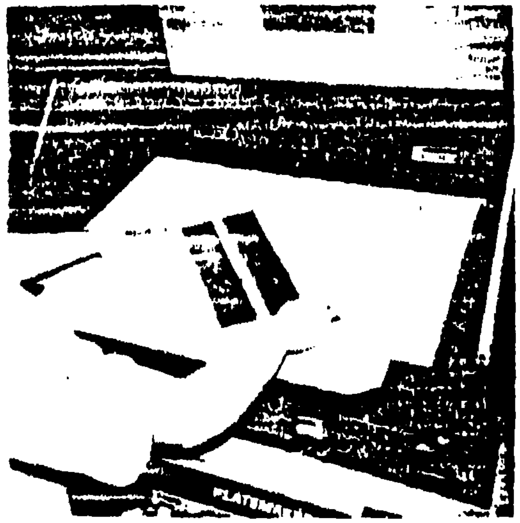


Figure 43. Exposing Diazo Film

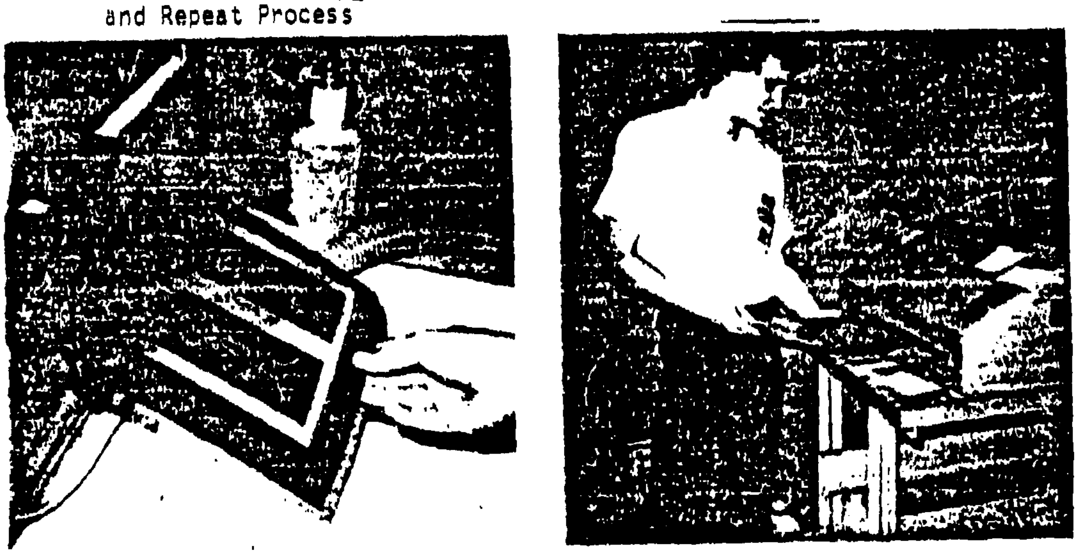
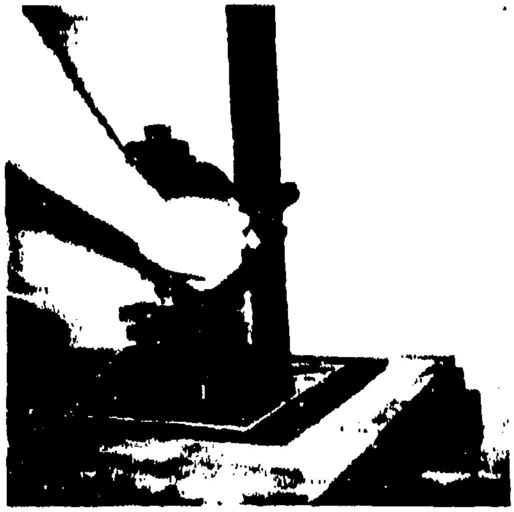


Figure 44. Developing Diazo Film

2078-50

Figure 45. Registering Film on Artwork Template



2078-51

Figure 46. Punching Loose Film Holes on Working Film

2078-52

Figure 47. Touching Up Working Film

For each side of film, the above process is followed. Most printed wiring board facilities have the capabilities to reproduce masters in the above manner. A step and repeat camera may be used rather than the manual method, but because of high capital investment costs this type of equipment was not obtained.

RESIST EXPOSURE

An experiment was conducted to establish a production method for handling the glass master. Of first importance, the PC-24 expose unit vacuum system had to be modified slightly so as not to pull more than 8 pounds of vacuum, to prevent glass breakage. This consisted of putting a bleed valve in the main vacuum line to a tray. Also, a fixture with cutouts had to be designed to hold the glass flush to the registration pins during vacuum drawdown, or this, too, would damage the glass master (Figure 48). Once this was done, the glass was used to expose test panels. Results from this study are:

- Line width expected - 0.031230
- Line width observed after etch:

  0.031828
  0.030989
  0.031784
  $X = 0.031534$
  $\Delta = 0.0003$

The same experiment was conducted with a diazo mylar film set. The vacuum system used was identical to that used in conventional printed wiring board imaging. Results from this portion are:

- Line width expected - 0.031230
- Line width observed after etch:

  0.03152
  0.03202
  0.03176
  $X = 0.031767$
  $\Delta = 0.00054$

Another important feature of the artwork reproduction is registration. After etching, microsections were made of each sample to observe layer to layer effort at the point of coupling, as depicted in Figure 37. The expected offset was 1.0 X 10^{-4} inches. The microsectional analysis is given below:

Glass Offset	Diazo
0.000180	0.00058
0.000386	0.00039
0.000386	0.00066
0.000325	0.000542

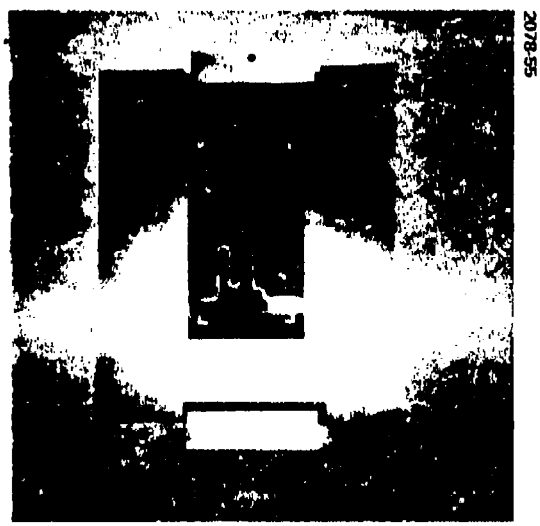


Figure 48. Example of Glass Master and Support Fixture

In conclusion, the glass performed better in all aspects of line delineation and geometric characteristics location than the mylar phototool.

The main disadvantage of glass is its high replacement cost. But with proper handling procedures the life of a glass master may prove to outweigh its high cost.

Current advances in glass master fabrication techniques have made reproduction of conductor configuration and geometrical feature retention considerably finer. However, without all processes strictly controlled, no matter how

accurately an artwork image is reproduced on a glass master, processing errors can be significantly greater. With increasing process control capabilities, glass master and glass master working tools will be of prime consideration in stripline fabrication. For the remainder of this program, diazo working film was used.

In an attempt to provide Canoga Park with deliberately misregistered 3 dB quad stripline components, several artwork sight templates were fabricated. Each of them differed slightly in the location of the lay-up tooling holes (targets) as described in Table 5; where the X direction represents the longitudinal direction of the 3 dB quad (Figure 35).

Each of the four films described above was used as the front side pattern, while a zero offset pattern was used as the rear side. Unfortunately, the actual offset differed significantly from the observed offset as determined by microsectional analysis along both the X and Y axis. The data obtained are listed in Table 6.

TABLE 5. TOOLING HOLE OFFSET

	X	Y
1.	0.0000 inches	0.0030 inches
2.	0.0000 inches	0.0060 inches
3.	0.0060 inches	0.0000 inches
4.	0.0060 inches	0.0000 inches

2078-53

TABLE 6. MICROSECTIONAL ANALYSIS RESULTS OF TOOLING HOLE OFFSET

ANTICIPATED		OBSERVED			
		WOVEN		NON-WOVEN	
X	Y	X	Y	X	Y
0.0000 in.	0.0030	0.0006	0.0009	0.0008	0.0009
0.0000 in.	0.0060	0.0011	0.0016	0.0069	0.0033
-0.0060 in.	0.0000	0.0031	0.0040	0.0042	0.0039
0.0060	0.0000	0.0052	0.0027	0.0066	0.0011

2078-54

As was mentioned in the resist selection section, the 0.0015 inch resist was selected for use in this program as a result of its initial performance of expose level measured in mJ/cm^2 versus conductor width reproduction.

From Figure 40 the equation of the line,

$$Y = 2036.95 \pm 578.19 \ln X \tag{12}$$

where

X = final conductor width in inches, and

Y = predicted expose level in mJ/cm^2

was solved for $X = 0.03398$, the actual artwork line width. Therefore,

$$\begin{aligned} Y &= 2036.95 \pm 578.19 \ln (0.03398) \\ &= 2036.95 \pm 578.19 (-3.38) \\ &= 2036.95 \pm (-1955.43) \\ &= 81.52 \ mJ/cm^2 \end{aligned}$$

In conclusion, for 0.0015 inch dry film resist, an exposure level of 81.52 mJ/cm^2 was necessary to obtain the actual line width of 0.03398 inch. As a method of determining expose level and film speed of the photoresist, ultraviolet-visible (UV-VIS) spectrophotometry was used. This investigation illustrates a new technique in optimizing the exposure process and should be a viable aid in production control.

The chemical reaction that occurs when a photoresist is exposed by subjecting it to intense ultraviolet radiation can be depicted as:

$$M_2 + M_3 \xrightarrow[\lambda = 360 \text{ nm}]{M_1,\ E} M_2M_3 \tag{13}$$

where

M_1 = reaction catalyst,

M_2 = unexposed open ended reactant monomer,

M_3 = unexposed single-open ended monomer,

M_2M_3 = reaction product, and,

$$\xrightarrow[\lambda\ =\ 360\ nm]{E} = \text{driving force of the reaction}$$

The proposed reaction goes to completion when sufficient energy has been absorbed so that all M_2 and M_3 monomers have reacted to form the M_2M_3 polymer. This energy term is given by:

$$E = I \times t \qquad (14)$$

where

E = energy expressed in mJ/cm^2

I = intensity expressed in mW/cm^2

t = exposure time expressed in seconds.

Therefore, by determining the relative degree of reaction as a function of incident energy, the exposure process can be quantified independently of resist processing.

The magnitude of the energy incident on the resist may be determined by measuring the output intensity of the exposure unit and the duration of the exposure. Since the reaction product is strongly absorbing in the UV region, the quantification of the relative degree of reaction can be obtained using UV/VIS spectrophotometry.

The PC24 expose unit's top tray lamp intensity incident on the vacuum frame (i.e., no film was used) was mapped. The range of intensity was found to be from 13 to 17.7 mW. Isometric lines were drawn to represent mJ/cm^2 based on a constant exposure duration (see Figure 49). A maximum deviation of 20 mJ/cm^2 can be observed over the entire PC24's top frame, top lamp. By exposing in the upper center portion of the unit, exposure energy will remain constant. Exposures taken close to the front or at the sides of the tray will be significantly lower than the rear, and will affect critical line replication.

Eight samples were taken from a 400 foot roll of 0.0015 inch resist using a specially fabricated resist slide holder. Each sample was placed sequentially in the center location of the PC24's top vacuum frame and exposed from

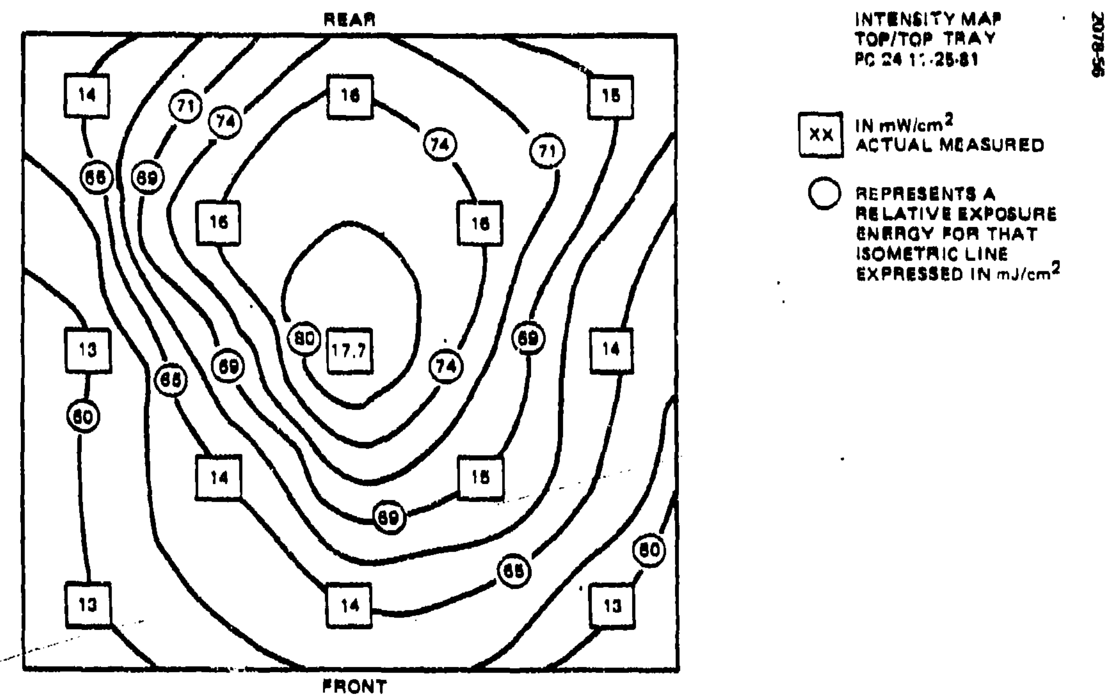


Figure 49. Light Intensity Distribution over Entire Expose Area

the top for increasing durations (see Table 7). After exposures, the samples were immediately taken to the process control laboratory in a sealed light-proof bag for analysis.

TABLE 7. INCIDENT ENERGY (E) (I = 17.7mW/cm^2)

SAMPLE	EXPOSURE SECONDS	INCIDENT ENERGY E(mJ/cm^2)
A	1	17.7
B	2	35.4
C	3	53.1
D	4	70.8
E	5	88.5
F	6	106
G	7	124
H	8	142
I	0	0

2078-57

A Perkin-Elmer UV-VIS Spectrophotometer Model No. 552 was then used to determine all spectral responses of the resist. When sampling the unexposed resist, no reference cell was used. In all other cases, a sample of unexposed resist was used as the reference cell.

Figure 50 presents a spectral scan of the unexposed resist. The prominent features of this scan are:

1) Absorption peak at 620 nm.

2) Continual absorption of light below 400 nm.

3) Shoulder at 330 nm.

The absorption peak at 620 nm represents the dye used in the resist. The dye is not chemically related to the reaction product polymer but is a visual aid in identifying unexposed and exposed resist. The continual absorption of light below 400 nm and the shoulder at 330 nm represent the catalyst and M_2, M_3, or both (from Equation 9). The isolation of single component peaks cannot be done since an incomplete data set exists at this time. If a greater data base can be obtained, it may be possible to use a standard spectrum of a known "good" resist sample to compare an incoming resist lot for defect. This technique could provide a practical method for incoming resist inspection.

Next, an exposed resist sample was placed in the cell and a continuous scan taken. It is considerably different from the unexposed resist because of the presence of the reaction product M_2, M_3 in the 314 to 317 nm range (see Figure 51).

The remainder of the samples of resist exposed for various durations were each subjected to UV absorption analysis at 315.5 nm. The results obtained are shown in Figure 52 and Table 8.

Based on this investigation, it is possible to calculate the best exposure setting for a given resist lot by measuring the intensity output of the exposure unit lamps, exposure duration, and the UV response of a sample specimen. For constant exposure the absorbance values should not change for a given sample of resist. However, lot variations in resist film speeds may

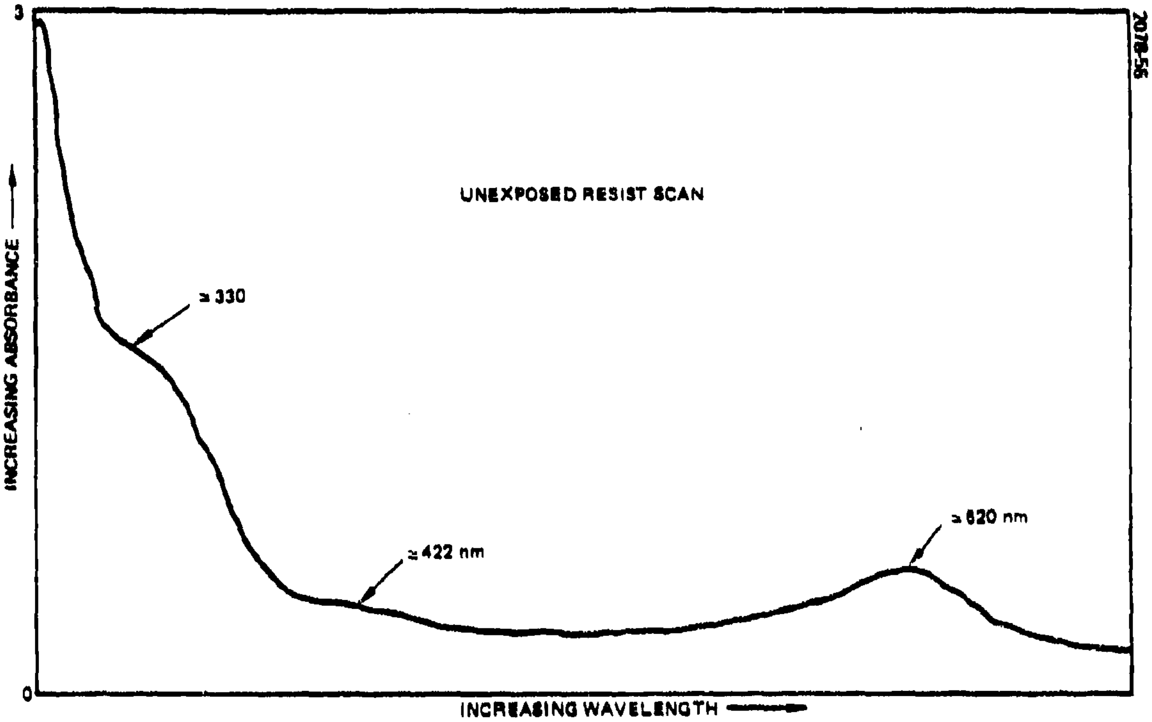


Figure 50. Ultraviolet-Visible Scan of Unexposed Resist

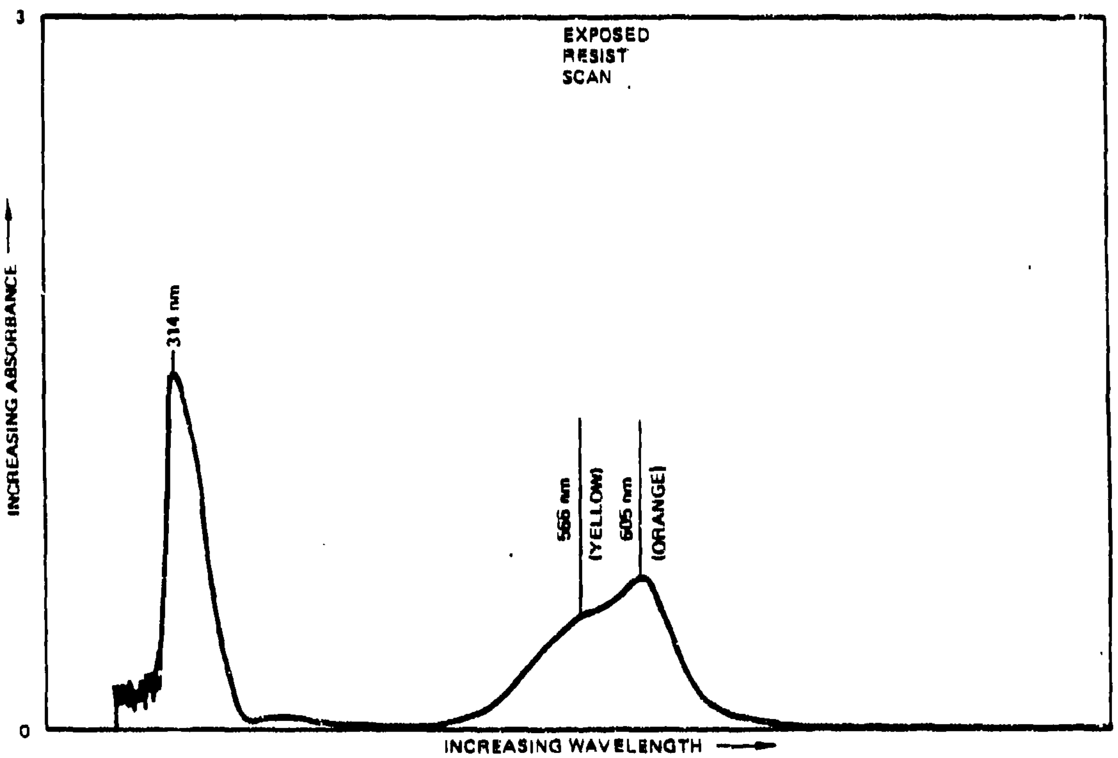


Figure 51. Ultraviolet-Visible Scan of Exposed Resist

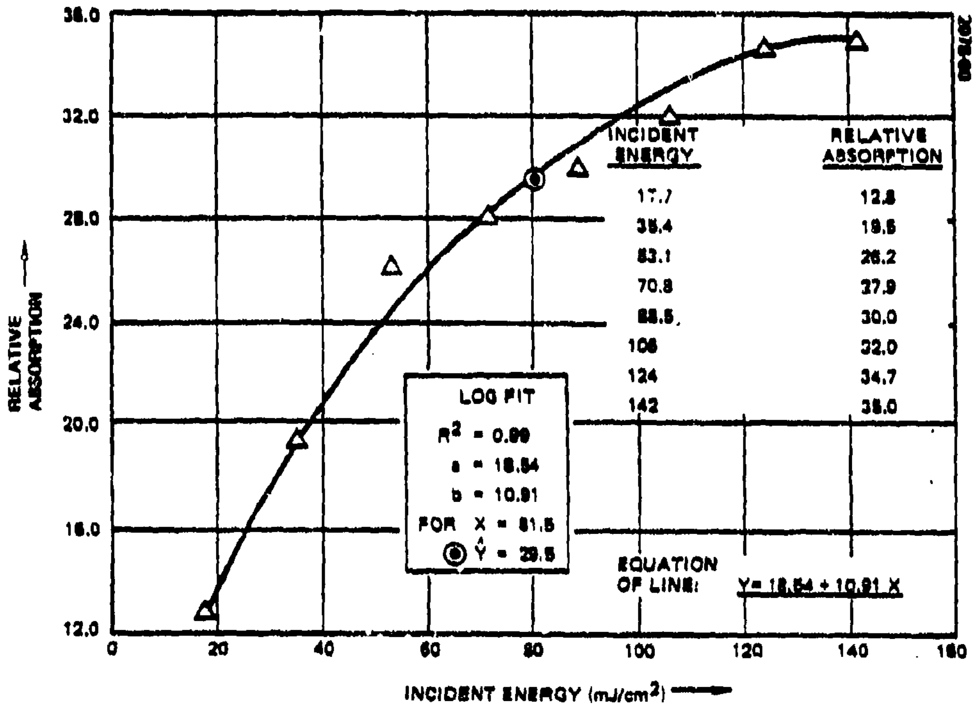


Figure 52. Relative Absorption of Resist versus Incident Energy

TABLE 8. RELATIVE ABSORBANCE VERSUS
E (0.0015 INCH RESIST)

SAMPLE	$E (mJ/cm^2)$	RELATIVE ABSORPTION
A	17.7	12.8
B	35.4	19.5
C	53.1	26.2
D	70.8	27.9
E	88.5	30.0
F	106.0	32.0
G	124.0	34.7
H	142.0	35.0

2078-81

offset the absorbance values. From the standard curve a compensation factor in exposure energy can be established to ensure repeatable exposures from lot to lot of photoresist.

RESIST PROCESSING

Based on prior sections of this report, accurate and repeatable process control is necessary to maintain the line delineation required of stripline components. Resist processing or development is not immune to these requirements.

To establish optimum processing techniques, an experiment was conducted to establish the development time that would be required to reproduce a calculated exposure level (in mJ/cm^2) while all other variances were held constant. These constants were exposure energy (93 mJ/cm^2), developer temperature, and spray pressures (see Table 9). Board surface preparation techniques were conducted as described in the microetch section of this report. Resist lamination processes were conducted as mentioned earlier.

After resist lamination the boards were held 15 minutes before exposing to allow for sufficient cooling of the polymer. The calculated exposure setting was 93 mJ/cm^2 based on the Riston 17 step density tablet or gray scale. This gray scale measures exposure energies by allowing resist polymerization on only those areas where the energy is great enough to exceed the density of the scale. The results from this study indicate that an 81 second development time was necessary to obtain the calculated exposure energy. It also proved that an underdeveloped sample will show an apparent increase in exposure while an overdeveloped sample will show an apparent decrease in exposure (see Figure 53 and Table 10).

Since surface preparation affects resist adhesion and hence can change apparent exposure energies, an experiment was conducted to quantify this after processing. While holding development processing variables as established earlier in this section, various board surface preparation techniques were tried and their relation to exposure energy directly observed.

TABLE 9. DEVELOPMENT TIME

DEVELOPMENT TIME ~ 68°F		
SPRAY PRESSURE CHAMBER	1	= 30 lbs.
	2	= 15 lbs.
	3	= 15 lbs.
WATER RINSE	4	= 15 lbs.
EXPOSURE = 90mJ		
RESIST = 0.0015 inch		

2078-62

TABLE 10. OPTIMUM DEVELOPMENT TIME

PROCESSOR SPEED, SECONDS	EXPOSURE OBSERVED, mJ/cm^2
69	97.5
79	83.9
81	93.0
84	97.5
88	83.9
92	79.4
98	79.4
OPTIMUM DEVELOPMENT TIME = 81 SECONDS	

2078-64

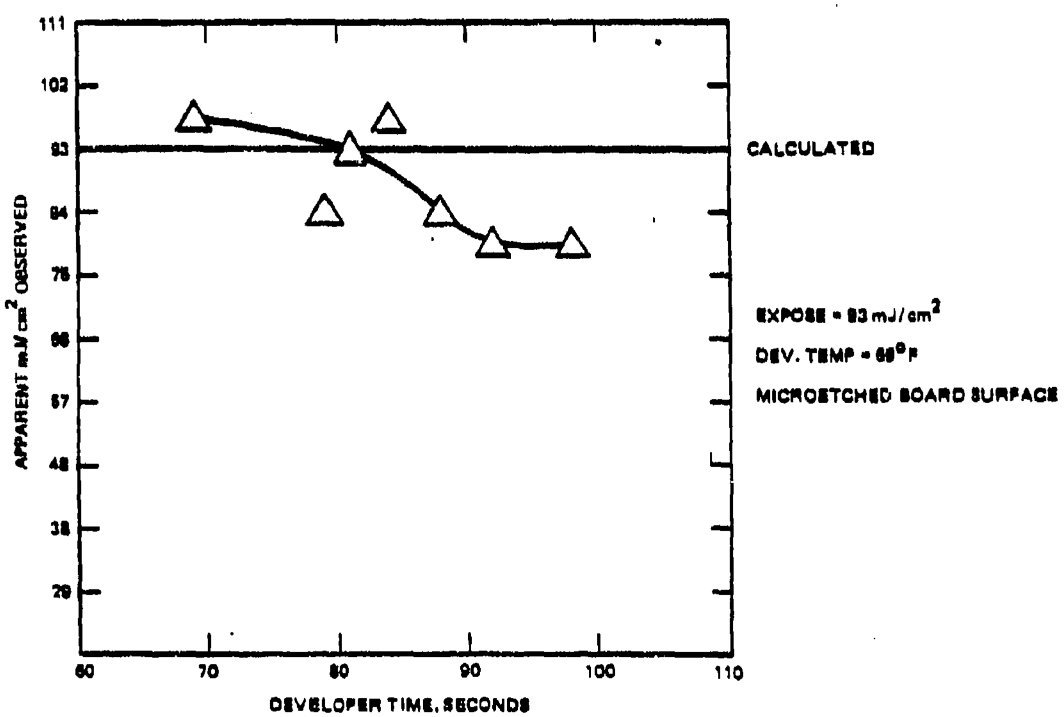


Figure 53. Developer Speed versus Apparent Exposure

Four types of board surface preparation techniques were tested. These were:

1) Mechanical brush scrubbing using 3M-600 grit brushes (Figure 54).

2) Vapor honed/electroless plated (Figure 55).

3) Oxide treated (Figure 56).

4) Microetched (Figure 57).

The expected exposure energy held after all processing was 93 mJ/cm^2.

The results of this study indicate that the microetched and vaporhoned/electroless plated surfaces provided the most uniform surface for optimum resist processing. The oxide treated surfaces provide good results while the mechanically scrubbed surface showed random results (see Figure 58).

ETCHING

Currently, Hughes Tucson utilizes a DEA 24 inch conveyorized etch and clean system with alkaline etchant chemistry. Other etchants and machine designs were not tested during this program.

The typical alkaline etching parameters for conventional printed wiring board fabrication were used in etching all stripline substrates. These nominal values are:

Temperature	=	120°F
Copper Concentration	=	20 oz/gal
Halide Concentration	=	5.3 moles per liter
pH	=	8.4

The conveyor speed was adjusted as necessary, utilizing boards of similar copper thickness as the stripline substrates. Typical etch rates were between 1.4 and 1.6 mils/min at 120°F. The reason for this large fluctuation in etch rate can be attributed to inadequate control of etchant solution chemistry as

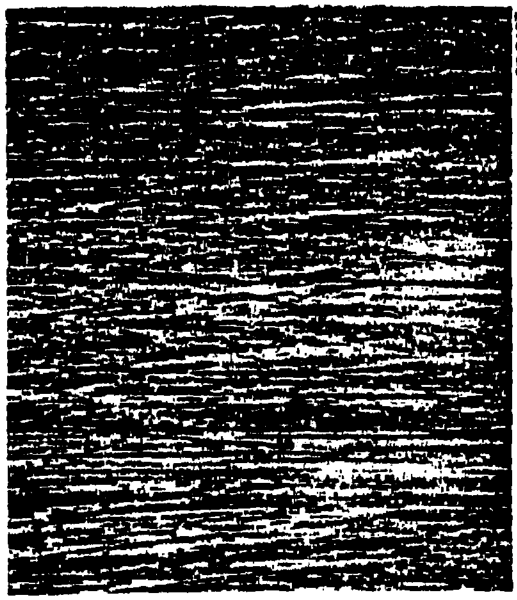


Figure 54. Mechanically Scrubbed Copper Surface (100X)

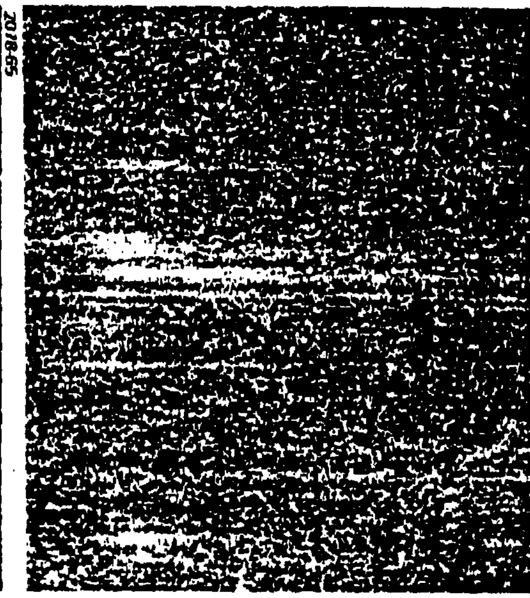


Figure 55. Vapor Honed/Electroless Copper Deposition Surface (100X)

Figure 56. Oxide Treated Copper Surface (100X)

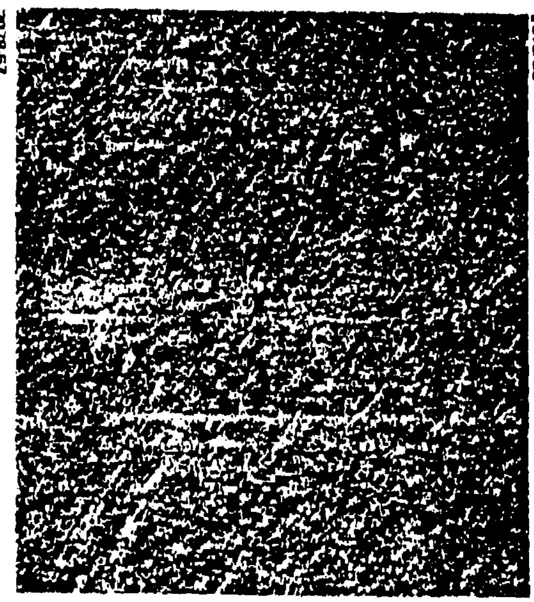


Figure 57. Microetched Copper Surface (100X)

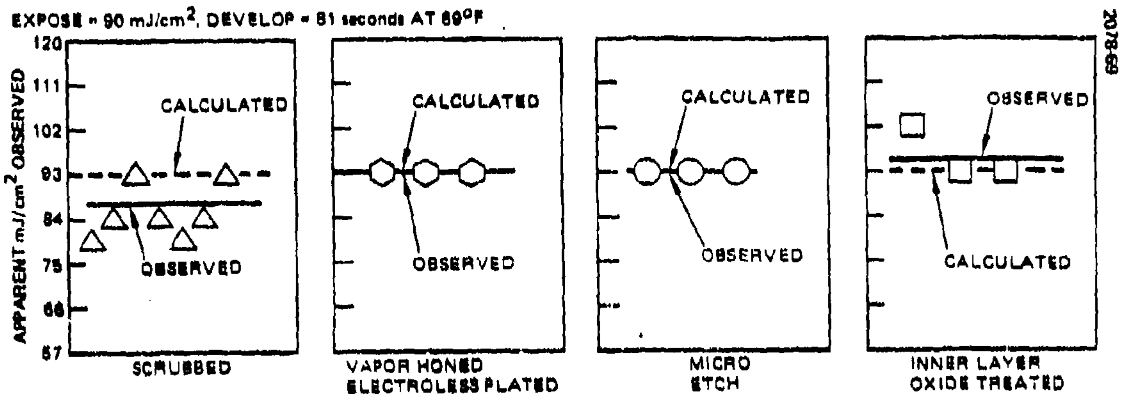


Figure 58. Board Surface versus Apparent Exposure Energy

depicted in Figure 59 and Table 11. These fluctuations are typical in systems controlled by specific gravity alone as is the system used in this investigation. Excessive decreases in pH caused by evaporation of ammonia and decreases in halide concentration due to complex formation with copper can be minimized by operating the system continuously.

Continuous operation allows smaller replenishment additions and reduces control lag. The system used in this investigation was not operated continuously. At start up the pH, halide, baume, and copper concentration were measured and approximate bulk additions were made to establish the bath at nominal control limits. The result is the discontinuity in etchant chemistry stability as seen in Figure 59.

By using sample panels to set conveyor speeds, these deviations in chemistry imbalance were compensated for and excellent etching characteristics were achieved. Undercut factors were measured and found to be typically less than 0.0005 inch (see Table 12).

Data analysis was conducted on a sample of thirty-two 3 dB quad circuit traces to determine the line width after etching utilizing the previously established optimum processing techniques (Table 13). The expected line width was 0.03123 inch. The average observed line width was 0.03170 or +0.00047 inch deviation. Table 14 depicts the percent yield based on decreasing acceptable line width deviations.

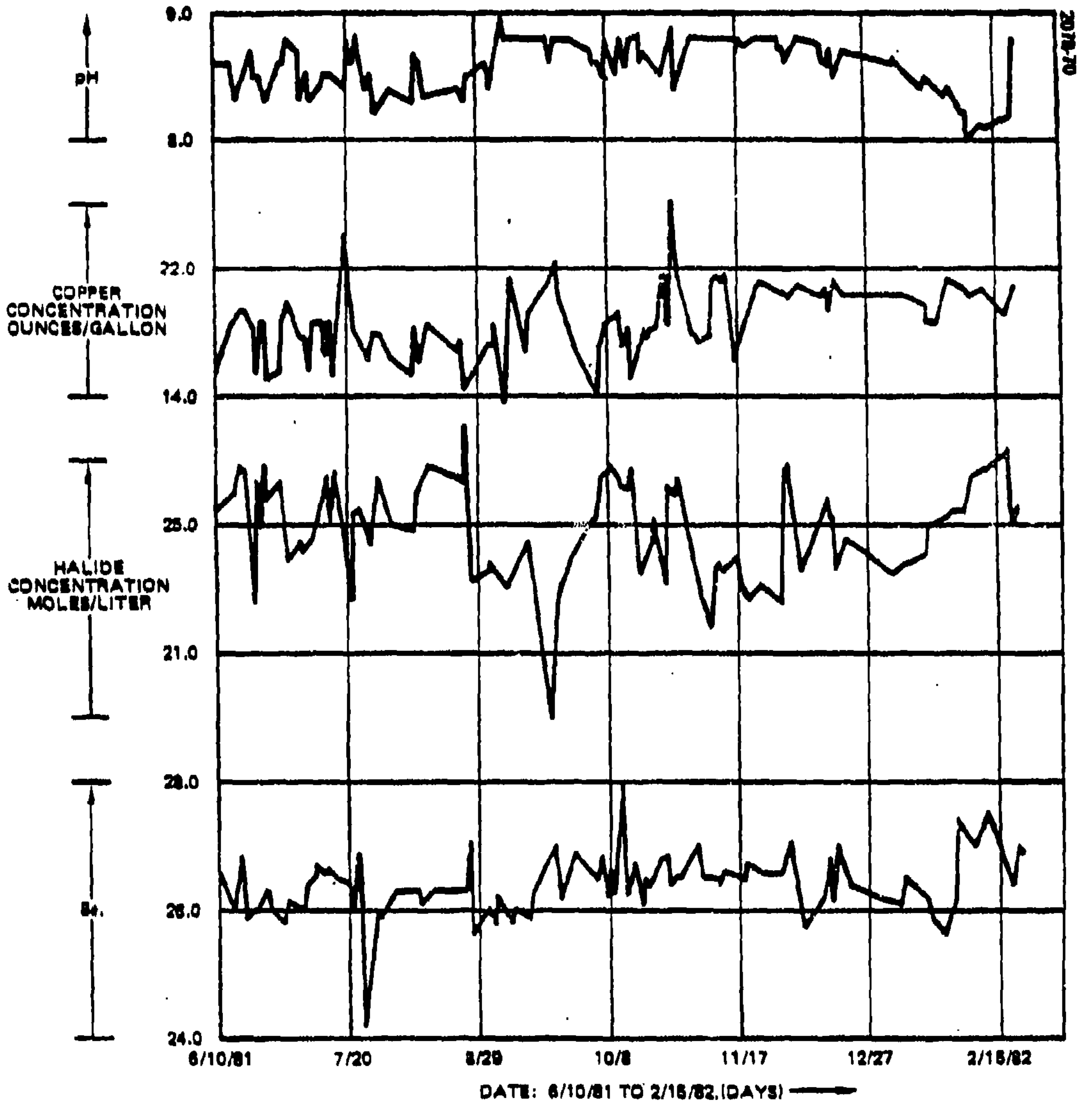


Figure 59. Alkaline Etchant Chemical Stability

As can be seen in the data from Table 14, as line tolerances decrease effective yields also decrease. More stringent control of line replication technique needs to be developed to increase yields on those circuit traces requiring 1 to 1 replication through the etching process.

TABLE 11. ALKALINE ATTACHMENT DATA

DATE	pH	Cu	HALIDE	Be	DATE	pH	Cu	HALIDE	Be
6/10/81	8.2	18.6	25.4	26.5	10/08/81	8.5	18.6	26.5	27.0
6/11/81	8.5	16.0	25.5	26.5	10/09/81	8.8	18.6	26.8	26.3
6/15/81	8.6	18.6	25.9	26.0	10/12/81	8.5	19.4	26.4	28.0
6/16/81	8.5	18.8	26.0	26.4	10/13/81	8.8	17.0	26.2	26.2
6/17/81	8.3	19.0	26.4	26.8	10/15/81	8.6	18.2	26.1	26.5
6/18/81	8.4	19.4	25.8	26.0	10/16/81	8.8	15.2	26.8	26.8
6/19/81	8.5	19.4	26.7	25.0	10/19/81	8.8	17.4	23.5	26.5
6/22/81	8.7	18.2	22.6	26.0	10/20/81	8.6	18.2	23.8	26.4
6/23/81	8.6	15.4	26.4	26.1	10/21/81	8.7	17.0	24.0	26.6
6/24/81	8.5	18.6	25.0	16.2	10/22/81	8.6	18.2	24.5	26.6
6/25/81	8.4	18.6	26.8	16.3	10/23/81	8.55	18.4	25.1	26.8
6/26/81	8.3	15.0	25.9	16.0	10/26/81	8.50	22.0	23.12	26.9
6/30/81	8.6	15.6	26.4	16.8	10/27/81	8.6	18.6	26.2	26.4
7/01/81	8.6	19.2	25.1	26.1	10/29/81	8.9	26.0	26.0	26.5
7/02/81	8.8	19.8	23.9	16.1	10/30/81	8.4	21.6	26.4	26.5
7/03/81	8.7	17.7	24.5	26.0	11/04/81	8.8	17.8	23.6	27.0
7/07/81	8.3	17.8	24.1	26.4	11/05/81	8.8	17.4	23.2	26.7
7/09/81	8.5	15.4	24.5	26.5	11/06/81	8.8	17.4	22.6	26.5
7/10/81	8.3	18.6	24.6	26.7	11/09/81	8.8	17.8	21.7	26.5
7/13/81	8.4	18.6	25.9	26.6	11/10/81	8.8	21.2	23.5	26.5
7/14/81	8.5	16.8	26.5	26.6	11/11/81	8.8	21.4	23.7	26.4
7/15/81	8.5	18.6	25.0	26.5	11/12/81	8.8	21.2	23.5	26.5
7/16/81	8.5	15.2	26.5	26.7	11/13/81	8.8	21.4	23.6	26.6
7/20/81	8.4	23.4	24.5	26.4	11/17/81	8.8	16.2	24.0	26.5
7/21/81	8.8	20.2	24.4	26.0	11/18/81	8.7	17.2	24.2	26.5
7/22/81	8.6	19.4	22.6	26.4	11/19/81	8.8	17.6	23.0	26.7
7/23/81	8.6	18.2	25.9	26.7	11/21/81	8.75	18.2	22.6	26.75
7/24/81	8.8	15.0	25.5	24.2	11/24/81	8.8	21.2	23.1	26.6
7/27/81	8.4	16.4	24.2	25.2	11/31/81	8.8	20.75	22.5	26.6
7/28/81	8.5	17.2	25.1	25.6	12/01/81	8.8	20.4	22.6	26.7
7/29/81	8.3	18.0	26.0	26.0	12/02/81	8.7	20.6	26.7	26.9
7/30/81	8.2	15.0	26.5	25.9	12/03/81	8.6	20.2	26.8	27.0
8/03/81	8.4	16.5	25.0	26.3	12/07/81	8.8	20.9	23.5	25.7
8/10/81	8.3	15.2	24.3	26.3	12/14/81	8.7	20.4	25.4	26.2
8/11/81	8.7	18.4	26.0	26.1	12/15/81	8.6	20.6	26.0	26.8
8/12/81	8.6	16.0	26.2	26.2	12/16/81	8.6	19.4	25.2	26.2
8/14/81	8.35	18.6	26.8	26.3	12/17/81	8.7	20.4	24.2	26.8
8/24/81	8.40	17.0	26.5	26.3	12/18/81	8.5	21.2	23.5	27.0
8/25/81	8.40	17.4	26.4	26.5	12/21/81	8.7	26.4	24.5	26.4
8/26/81	8.3	14.4	28.2	27.0	1/05/82	8.6	20.4	23.5	26.10
8/27/81	8.5	15.2	23.2	25.6	1/06/82	8.65	20.4	23.6	26.4
9/02/81	8.6	17.4	23.6	26.0	1/07/82	8.6	20.4	23.7	26.5
9/03/81	8.5	17.2	23.8	26.8	1/14/82	8.4	19.8	24.0	26.2
9/04/81	8.4	18.4	23.6	26.2	1/15/82	8.5	18.6	25.0	25.0
9/08/81	9.9	13.5	23.1	25.8	1/18/82	8.4	18.6	25.1	25.6
9/09/81	8.8	21.2	23.5	26.0	1/21/82	8.35	21.0	25.2	26.2
9/14/81	8.8	16.8	24.5	25.9	1/22/82	8.40	21.4	25.4	27.4
9/15/81	8.8	19.4	24.0	26.3	1/26/82	8.2	0.5	25.4	27.0
9/21/81	8.8	21.2	18.8	27.0	1/27/82	8.2	20.6	26.0	27.0
9/23/81	8.6	22.4	22.6	26.2	1/28/82	8.0	20.4	26.5	27.0
9/24/81	8.8	20.0	23.2	26.4	2/01/82	8.1	20.6	26.8	27.5
9/28/81	8.8	17.0	25.1	25.9	2/02/82	8.1	20.4	26.8	27.3
10/05/81	8.7	14.0	25.3	26.5	2/08/82	8.2	20.6	25.0	27.0
10/06/81	8.6	17.2	26.1	26.8	2/11/82	8.8	20.8	25.5	21.9
10/07/81	8.6	18.0	25.5	26.2					

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TABLE 12. UNDERCUT DATA

SAMPLE NUMBER	UNDERCUT
1	0.000482
2	0.000470
3	0.000430
4	0.000588
5	0.000588
6	0.000457
7	0.000386
8	0.000337

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TABLE 13. LINE WIDTH FREQUENCY

VALUE	COUNT	PERCENT	VALUE	COUNT	PERCENT	VALUE	COUNT	PERCENT
0.03032	1	3.1	0.03124	1	40.6	0.03218	1	75.0
0.03081	1	6.3	0.03152	1	43.8	0.03231	1	78.1
0.03083	1	9.4	0.03161	1	46.9	0.03246	2	84.4
0.03097	1	12.5	0.03163	1	50.0	0.03258	1	87.5
0.03098	1	15.6	0.03176	1	53.1	0.03210	1	90.6
0.03101	1	18.8	0.03194	1	56.3	0.03272	1	93.8
0.03104	1	21.9	0.03198	1	59.4	0.03277	1	96.9
0.03105	1	25.0	0.03202	1	62.5	0.03287	1	100.0
0.03109	3	34.4	0.03209	1	65.6			
0.03120	1	37.5	0.03218	2	71.9			

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TABLE 14. LINE WIDTH DEVIATIONS

DEVIATION FROM ACTUAL	RANGE	PERCENT WITHIN DEVIATION
±0.0010	0.03223 – 0.03023	75.0
±0.0005	0.03173 – 0.03073	40.6
±0.00025	0.03148 – 0.03098	28.2
	0.03143 – 0.03103	
±0.0001	0.03133 – 0.03113	18.7
±0.00005	0.03128 – 0.03118	3.1
±0.0020	0.03273 – 0.02873	93.8
±0.0015	0.03323 – 0.02823	100.0

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SECTION IX
MACHINING

INTRODUCTION

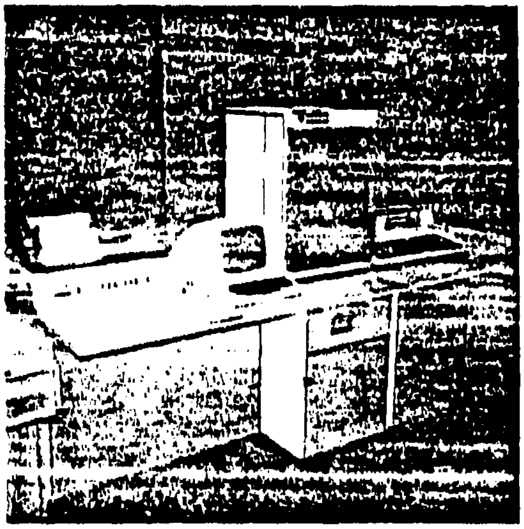
As previously suggested, the manufacture of RF stripline involves a series of diverse steps and processes. Board machining represents one of the key steps in achieving a reproducible fabrication process with the precision demanded by RF stripline components. The RF striplines were fabricated using an Excellon III numerical control drill machine and an Excellon Route Master numerically controlled router. The capabilities of the N/C drill machine with regard to expected accuracy and repeatability (consistency) had been previously investigated (see Appendix C). The study indicated that the individual axis deviation (not the true position, which is a composite of two separate axis) was approximately 0.0004 inch. The accuracy and repeatability of the N/C router are currently being investigated. A substantial database is not available for reporting at this time.

N/C IMPLEMENTATION

The following sections offer a brief summary of the procedures involved in the CAD/CAM - assisted output of N/C drill and route programs.

The CAM system at Hughes Tucson consists of a CV Model CGP100 CPU and tape drive (Figure 60), as well as peripheral equipment including the CV 19/3 Graphics Terminal (Figure 61), Decwriter Keyboard and Numeridex 9800 Punch, and the Versatec Plotter.

In the initial step of the implementation procedure, Hughes Tucson was supplied with a CAD database in the form of a magnetic tape. From the supplied database, the information that is pertinent to N/C drill and route implementation, i.e., the location and size of drilled holes and the board contour, was extracted (Figure 62). This information then becomes the basis for the CAM database from which the N/C drill and route programs, in the form of machine readable EIA paper tapes, are created.



2078-75

Figure 60. CPU and Tape Drive

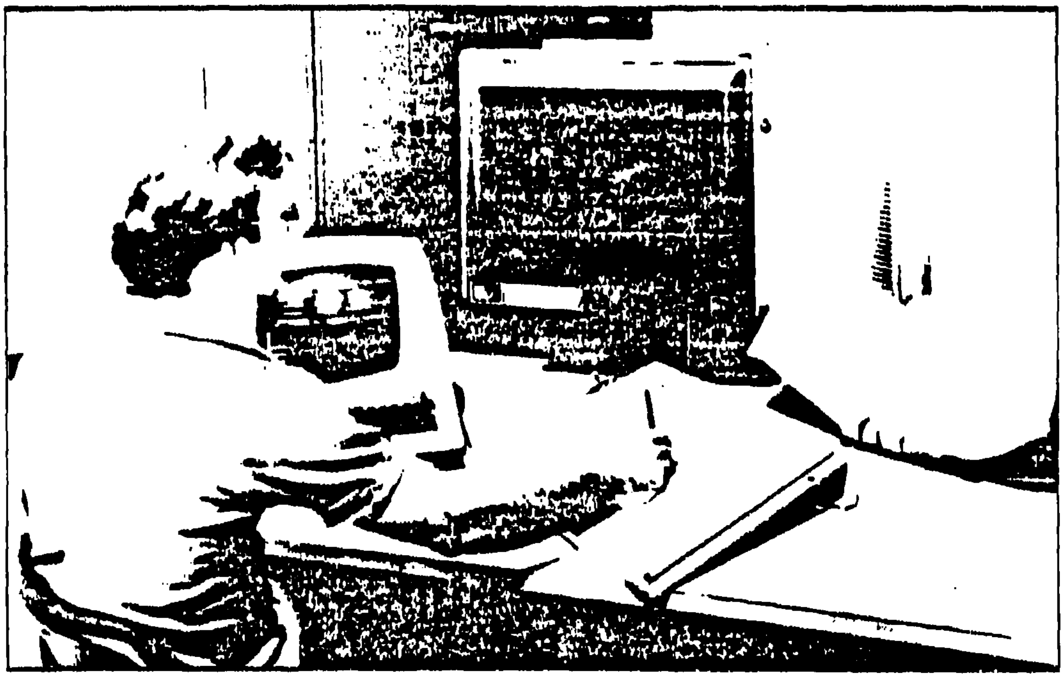


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Figure 61. Graphics Terminal

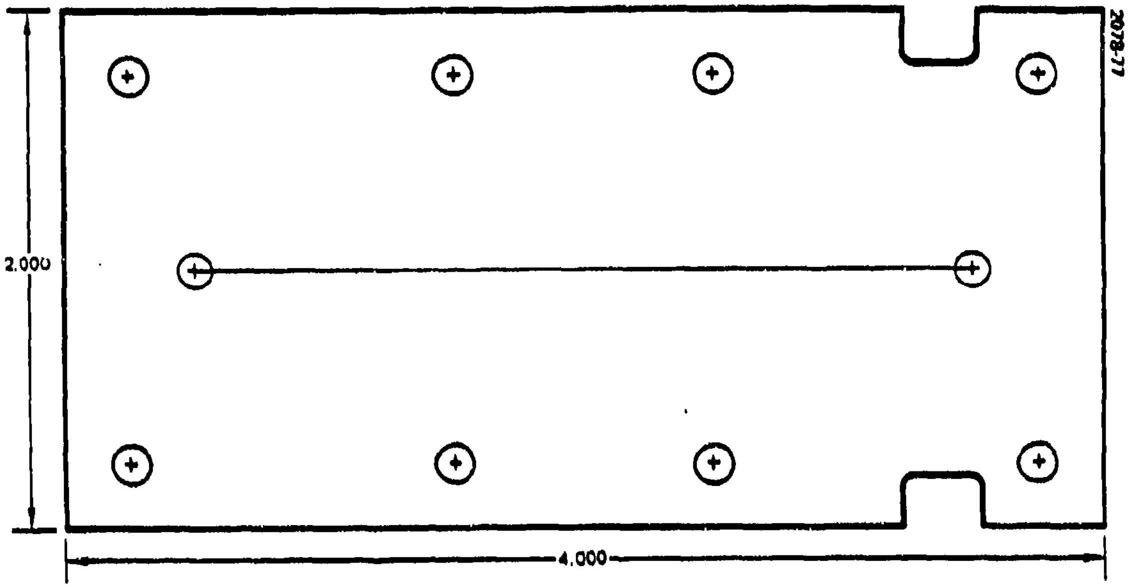

Figure 62. Extracted CAD Data

The CAM database is built using the information extracted from the CAD database as well as several prebuilt library parts, including test patterns and panel representations that have been preorientated to the Excellon III machine zero. The panel representation is inserted into the database, and the board is moved onto the panel. Copies of the board are then arranged on the panel in such a way as to provide a symmetric layout for artwork registration and pattern plating (Figure 63). If test patterns were required, they would be inserted at this time with appropriate hole size properties. Next, holes of each size are sorted with respect to other holes for the same size, and optimum machine paths are constructed for each tool (Figure 64). Then information in each CAM toolpath is processed. Machine codes including tool changes, step and repeats, and machine feeds and speeds are also added. The finished product is a text file that is punched on a machine-readable EIA paper tape. The accuracy of the production tape is then verified, and templates, including one for artwork registration, are produced.

Router programs are created, using the same CAM database. First, a copy of the board contour is moved a predetermined amount off the panel to compensate for the differences in machine zeros from the drill to the router.

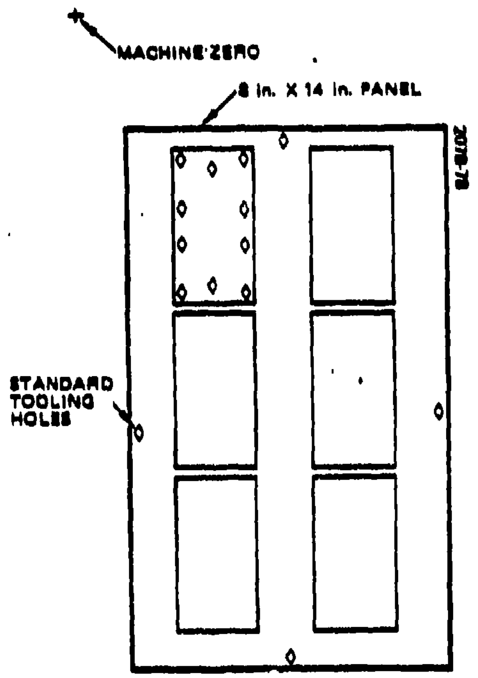

Figure 63. Automatic Step and Repeat of Hole Listing on Processing Panel

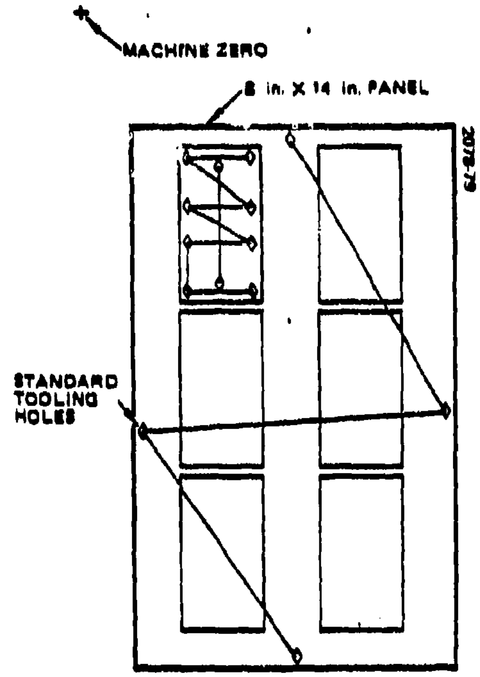

Figure 64. Construction of Drill Tool Path

Next, a modified, vendor-supplied tooling program is executed by digitizing each entity composing the board contour (Figure 65). Machine steps and repeats, as well as machine feeds and speeds, are inserted directly during execution of the program. Finally, the machine-readable EIA paper tape is punched using a vendor supplied postprocessor. The accuracy of the tape is once again verified and production contour verification templates are produced.

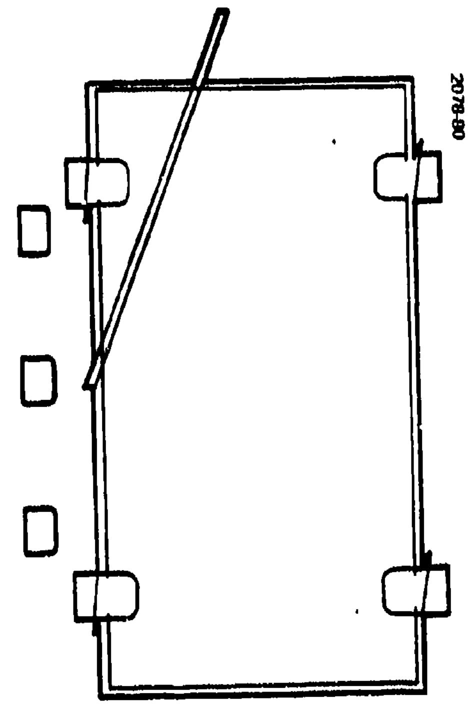

Figure 65. Construction of
Router Tool Path

SECTION X
MULTILAYER LAMINATION

Lamination in the usual printed wiring board application is the process by which individual inner layers, composed of a previously bonded dielectric material and copper with a circuit pattern etched into it, are bonded to one another by use of an adhesive. This lamination is performed in large platen presses under controlled temperature and pressure. During this process the adhesive fills all voids in the etched circuit patterns and bonds the individual layers together.

REGISTRATION AND TOOLING

Holding layer to layer registration of circuit pads during the lamination process is of major importance to the intended function of a printed wiring board. Registration is kept by the use of tooling pins and lamination fixtures (see Figure 66). Multilayer lamination usually requires multiple pinning to aid layer to layer registration. Location and configuration of the pins directly influence material shrinkage and panel size restrictions. The

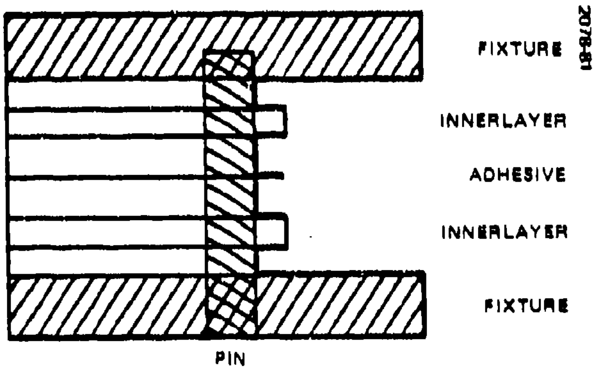

Figure 66. Lamination Fixture with Tooling Pin

optimum lamination fixture has an expansion rate which closely matches that of the inner layers to minimize the thermal stresses induced between them and the tooling pins. It must also be durable and remain hardened after many hours of thermal cycling. The fixture plates should be thicker than the tooling pin diameters for vertical stability and registration. A polished surface will provide for a smooth surface in contact with the outer layers which must still be imaged with a circuit pattern, thereby preventing voids caused by dents and scratches during lamination.

The most common platen presses are either steam or electrically heated. A hydraulic oil system provides pressure. Electric presses must be used when lamination temperatures in the 400°F range are required.

DETAIL HANDLING AND SURFACE PREPARATION

Besides layer to layer registration, another major concern for multilayer lamination is a product that is free of voids and laminated well enough to withstand all thermal shock requirements.

All adhesives, whether they are B-stage resins or bonding films, are easily contaminated with moisture, solvents and foreign material. Therefore, handling and storage procedures are very important to prevent delamination problems resulting from internal contamination. The maintenance of all adhesive properties such as flow, type, volatiles content, etc., is important to assure a consistently successful process. Therefore, receiving inspection of these properties is also an important consideration for any printed wiring board manufacturer.

Keeping the inner layers from contaminants is just as essential to avoid delamination as it is for the adhesive. Also of consequence, the surface of the inner layer must be prepared to optimally accept the adhesive so that bond strength will be at its maximum. For B-stage resins, the oxide-coated copper of the inner layers mechanically keys to the rough surface of the B-stage, giving acceptable peel strengths per the military requirements. For PTFE substrate printed wiring boards that are laminated using a bonding film, a surface etch must be performed on the PTFE material to promote adhesion.

LAY-UP PROCEDURES AND PRESS CYCLES

The multilayer bond package should be assembled in a clean room environment where temperature, humidity, and air quality are constant and controlled. A typical lay-up consists of the inner layer, made up of dielectric material and copper; adhesive sheets; the lamination fixtures with the appropriate tooling pin system; release sheets, which protect the fixtures from resin squeeze out if B-stage is used as the adhesive; and suitable padding, such as Kraft paper or a silicone rubber pad, which compensates for any deviations in press platen flatness and controls the rate of temperature rise in the laminate. To increase press capacity, more than one multilayer may be bonded by use of a stacking procedure where steel plates between the laminate stacks prevent circuit image transfer between them. The number of stacks possible is dependent on the heat transfer rate through the lay-up and the ability of the tooling pins to hold registration throughout the stacking (see Figure 67).

The press parameters of temperature (T), pressure (P), and time (t) are determined by the type of adhesive used. B-stage and bonding film manufacturers provide recommended procedures and cycles, but P, T, and t settings

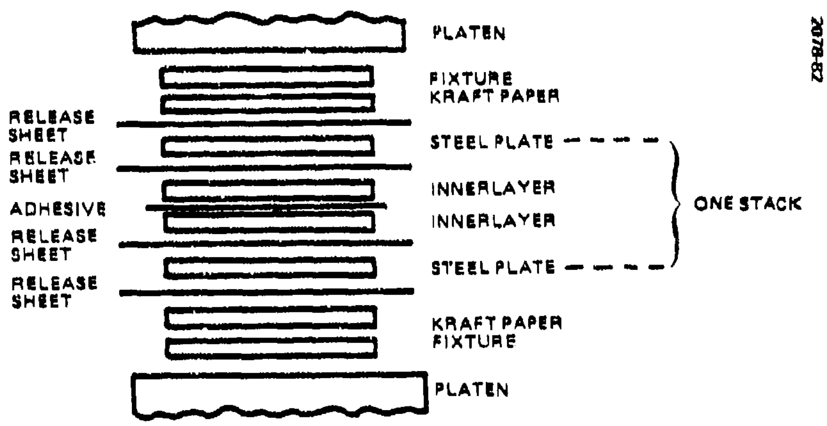

Figure 67. Typical Layup Scheme Showing One Stack

must be optimized for the individual printed wiring board fabricator under the following guidelines and goals:

1) The adhesive must flow so that circuit void areas are filled, and entrapped air escapes.
2) Initial pressures must clamp the individual layers in place, reducing laminate shift through the cycle.
3) The required degree of cure for B-stage resin or adhesion for bonding films must be reached through the correct combination of time and temperature.

Optimum press parameters may be verified visually by examining multilayers for measles and delaminations, and analytically by performing peel tests and glass transition temperatures.

STRIPLINE LAMINATION

The key requirements for the successful bonding of a multilayer is even more crucial for a stripline component. Layer to layer registration must be near perfect to assure effective stripline circuit coupling when the strips are on outer boards. A void-free product is also of major consequence to assure a uniform dielectric thickness and uniform dielectric constant throughout the stripline multilayer. Procedures after the lamination of a stripline multilayer are entirely dependent on the dielectric material used. This determines the surface preparation, type of adhesive, tooling lay-up sequence, and press cycles required.

Teflon microwave substrates are the typical dielectric materials used for stripline packages. In this study two types were used, woven and nonwoven glass reinforced.

Surface Preparation

Since Teflon, by nature, has low adhesion properties, surface preparation is very important for the stripline lamination process. Sodium etching the surface of fluorocarbons such as Teflon has proven very successful in promoting adhesion. The sodium compound in the etch solution reacts with the fluorinated polymer to form a reactive film on the Teflon surface, which gives

excellent bond strength and great versatility in types of adhesive that are compatible with it.

Types of Adhesive

The bonding film selected must reflect product end use. Expected temperature exposure and required delamination resistance determine the type of bonding film required. In this study, a fluorocarbon copolymer bonding film developed to match the dielectric constant of a particular laminate was selected. The film was 1.5 mils thick, allowing it to flow away from the copper pattern and give good bonding in the noncopper areas with minimum distortion of the laminate. Bond strengths possible with this film are in the 20 lb/in range if the laminates are properly treated prior to bond and the bond itself is properly performed.

Actual bond strengths observed were in the 3 to 5 lb/in. range. This resulted from unavoidable delays in performing the bond after surface preparation. Sodium etch tends to degrade with exposure to sunlight, UV radiation, heat, and moisture, all of which are present in a factory environment. It is recommended that in the future the lamination procedure be performed within 24 hours of sodium etch and the laminates be kept in a controlled environment.

Tooling for 3 dB Quad Fabrication

Since a small quantity of parts were scheduled for fabrication, a prototype bond fixture was made from aluminum sheets. Multilayer thickness requirements allowed for using 1/8 inch long pins, as described in Figure 68. Four pins were used for location. For this particular stripline configuration this was sufficient to meet registration requirements. For more complex striplines where coupling is required of more than one layer, a sophisticated pin system must be developed which allows for adequate material restraint to prevent shift and misregistration. Because this part was relatively small, dimensional change was not an observable problem.

Lay-Up Procedures

The lay-up sequence is described in Operations Directions 155 (Figure 69). Both laminate and adhesive were cleaned of contaminants by use of a vacuum system. Aluminum release sheets provide a clean and protected fixture surface and also match the thermal characteristics of the aluminum fixture. The Kraft paper

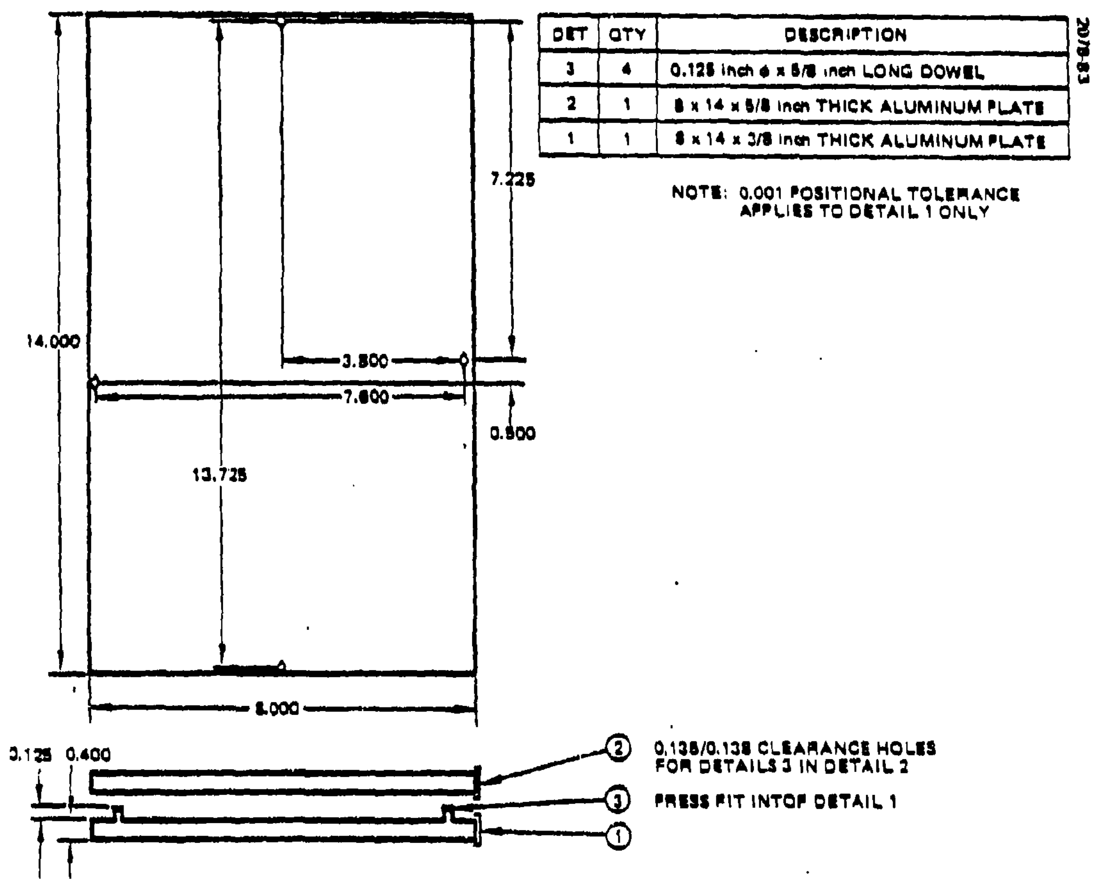

Figure 68. Bond Fixture Details

assured uniform pressure throughout the bond package and provided the recommended rate of heat rise for the bonding film. Since only a few parts were required, stacking to increase productivity was not considered. It is, however, a possibility for future work. Tooling pin accuracy will be the deciding factor if stacking is to become a consistently successful process improvement.

Press Cycle

Since the bonding film requires a lamination temperature of 425°F, an electric platen press was used. The press, Pasadena Hydraulics, Inc., Model 5100 MB, has been modified from steam heated to electrically heated for this purpose. Pressure is provided by a hydraulic oil system. Preset pressures and cure and cooling cycles are automatically engaged and timed out.

OPERATION DIRECTIONS – GENERAL PURPOSE **STATIONIZED PLANNING** SHEET OF

2078-84

1 PART NAME	2 PROGRAM	3 UNIT CODE	4 PART NO		5 OPERATION NO	REV
3DB QUAD COUPLER	STRIPLINE		MULTILAYER			
6 CONTROL CTR	7 WORK STATION	8 COOLANT	9 PLANNER	10 DATE		
5581	5040		M.M. ESCORZA	9-28-01	155	NC

11 REVISION DESCRIPTION	12 MADE BY	13 DATE

14 TAPE NO.	REV.	15 DNC JOB NO.	REV.

16

NOTE: Bonding must be performed within 24 hours of teflon etching.

Use following lay-up procedure:

TOP OF FIXTURE

Aluminum release sheet

TOP OUTER LAYER

1 sheet 3M 6700 adhesive

INNERLAYER

1 sheet 3M 6700 adhesive

BOTTOM OUTER LAYER

Aluminum release sheet

BOTTOM OF FIXTURE

Sandwich fixture between 3 sheets of kraft paper and load into preheated press.

Set press as follows for automatic cycle:

Temperature	= 425^{o}F
Pressure	= 20,000 pounds
Preheat Time	= 7 minutes
Cure Time	= 40 minutes
Cool Time	= 20 minutes

Figure 69. Operational Direction for Lamination of Stripline

Water cooling under pressure is provided. The final press cycle is described in Figure 69. The manufacturer's suggested cycle for the bonding film was used as a guide but adapted to conform to the lay-up previously described. The critical point in bonding with the copolymer film occurs when the laminate reaches 400°F. A thermocouple was inserted between the laminate to discover when this temperature was reached. After 20 minutes in the press, the bondline was at the critical temperature. The additional time assures that the bond is complete. No delaminations or unbonded areas were observed in the stripline package. When cutouts are present in the stripline, a suitable conformal layer must be used so that these areas will be under the same pressure as the rest of the package. Silicone rubber is ideal for these high temperature applications. If the cutouts are not conformally bonded, delaminations will occur.

DATA ANALYSIS

After successfully laminating the cover boards to the inner stripline circuits, a microsection of the effective coupler area was taken (Figure 70). The dimensional characteristics of this microsection are given in Table 15.

DIMENSIONAL STABILITY OF STRIPLINE MATERIALS

In an effort to understand the possible dimensional change that occurs in the Teflon microwave substrate material during processing, a dimensional stability study was performed on woven and nonwoven laminate under 0.020 inch thick. The thin laminate (0.0077 inch) was exposed to the etching process and subjected to an elevated temperature as described in the procedure for dimensional stability testing in MIL-P-13949F. The actual procedure closely follows the military specification and is described in detail below:

1) Scribe cross marks as shown in Figure 71.

2) Measure distance between cross marks and record "initial values" in X and Y directions.

3) Protect cross marks and etch in ammoniacal etcher and bake for one-half hour at 265°F.

TABLE 15. DIMENSIONAL CHARACTERISTICS OF BONDED MICROSECTION OF COUPLER AREA

C_u GROUND PLANE THICKNESS $_{TOP}$	0.0024 inch
STRIPLINE C_u THICKNESS $_{TOP}$	0.0017 inch
STRIPLINE C_u THICKNESS $_{BOTTOM}$	0.0017 inch
C_u GROUND PLANE THICKNESS $_{BOTTOM}$	0.0026 inch
DIELECTRIC THICKNESS BETWEEN STRIPLINE	= 0.0070 inch
DIELECTRIC THICKNESS BETWEEN TOP OF STRIPLINE CIRCUIT AND BOTTOM OF GROUND PLANE (INCLUDING 3M 6700) $_{TOP}$	= 0.0304 inch
3M 6700 ABOVE STRIPLINE CIRCUIT $_{TOP}$	= 0.0004 inch
3M 6700 BETWEEN DIELECTRICS $_{TOP}$	= 0.0013 inch
3M 6700 BETWEEN STRIPLINE CIRCUIT $_{BOTTOM}$	= 0.0016 inch
3M 6700 ABOVE STRIPLINE CIRCUIT $_{BOTTOM}$	= 0.0005 inch
DIELECTRIC THICKNESS BETWEEN TOP OF STRIPLINE CIRCUIT AND BOTTOM OF GROUND PLANE (INCLUDING 3M 6700) $_{BOTTOM}$	= 0.0305 inch
OFFSET $_{TOP\ TO\ BOTTOM}$ = 0.0006 inch	
LINE WIDTH = 0.03221 AVG.	

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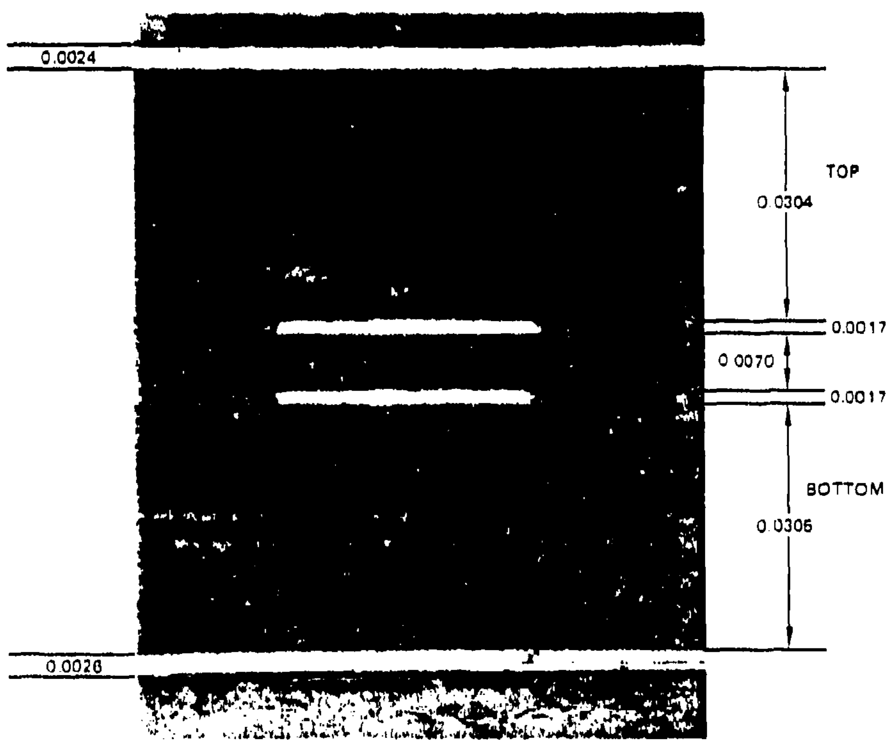

Figure 70. Microsection of Bonded Stripline Showing Coupler Area (50X)

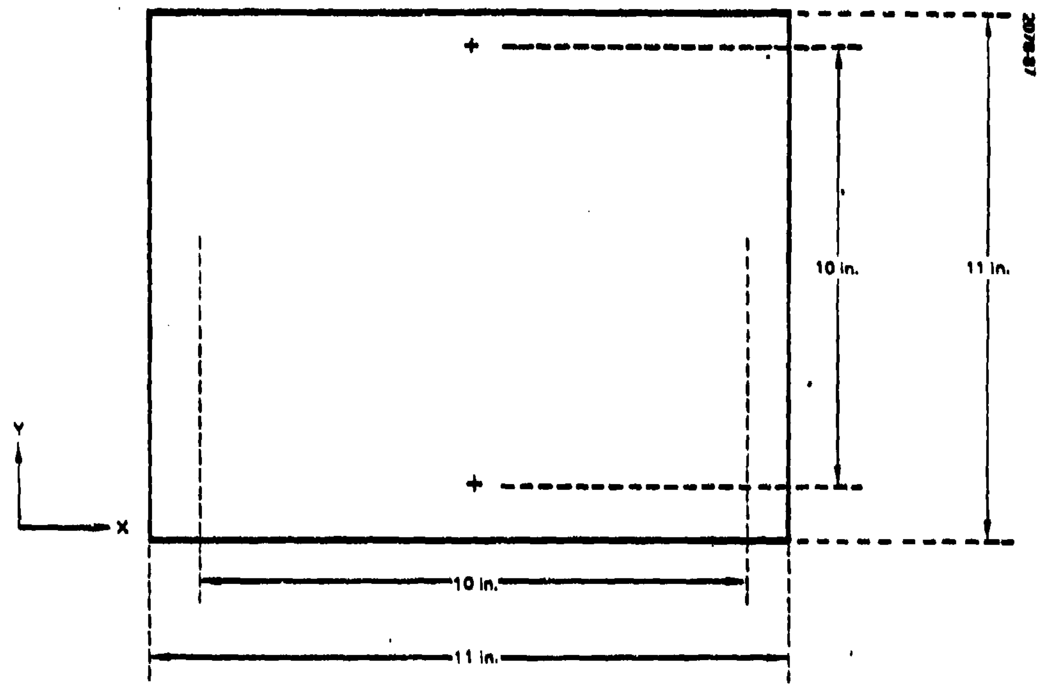

Figure 71. Crossmark Location for Dimensional Stability Testing

4) Stabilize by hanging vertically for 3 hours at 70° ±5°F and 45 ± 10 percent RH.

5) Measure distance between cross marks and record "after etch values" on X and Y directions.

6) Subject to elevated temperature. Hang vertically parallel to the oven air flow for one-half hour at 340°F.

7) Stabilize by hanging vertically for 3 hours at 70° ±5°F and 45 ±10 percent RH.

8) Measure distance between cross marks within 1 hour of stabilization and record "after elevated temperature values" in X and Y directions.

The X direction is set by the analyst. In this report it is always taken to be in the warp direction of the glass fiber, if applicable. Measurements were taken by "Supergage", which has an accuracy of ±0.0001 in/in. over the panel

size of 10 x 10 inches as required for this study. Actual data obtained from the procedure described above are presented in Table 16.

From this preliminary data it is obvious that Teflon substrates will show a considerable amount of shrinkage during processing. Observed inches per inch of change is considerably above the maximum allowed for polyimide and epoxy laminates in MIL-P-13949F. Dimensional change must be controlled if large stripline parts are to be fabricated successfully, or this fact must be taken into account in the design of future stripline packages and allowances made for it.

The unwoven laminate exhibited more shrinkage than the woven. Since the woven laminate is restrained by the glass cloth weave, it is obvious why this should be so. The warp directions of the glass cloth is especially stable. The fill direction closely matches the change exhibited by the nonwoven fabric in the arbitrarily chosen X-direction. Intuitively, the unwoven fabric should exhibit the same change in both directions. Since the Teflon is soft and pliable, this could be an effect of the vertical hanging procedure required for stabilization. Since the laminates were purposely hung along the same axis, less shrinkage in one direction could be a result of a growth effect caused by gravity.

Further work is required in this area to determine how the shrinkage can be reduced or eliminated and to quantify the net change observed in fully fabricated product. The quantified difference between woven and nonwoven stripline packages would also be useful information for both designers and manufacturers.

TABLE 16. DIMENSIONAL STABILITY TESTING RESULTS IN INCHES PER INCH OF CHANGE

		WOVEN	UNWOVEN
AFTER ETCH	X	-0.0002	-0.0021
	Y	-0.0020	-0.0042
AFTER ELEV. TEMP.	X	-0.0003	-0.0027
	Y	-0.0024	-0.0051

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SECTION XI
PLATING

For PTFE substrate plating of both edges and through holes, a surface etch must be performed on the PTFE material to ensure good plating adhesion. Sodium etching of the surface of fluorocarbons such as PTFE has proven very successful in promotimg plating adhesion. The surface film that results after sodium etching greatly enhances the plating adhesion.

Electroless copper deposition on PTFE substrate does not differ significantly from deposition on other materials except that the PTFE must be sodium etched. Another area of concern in electroless plating is ensuring adequate wetting of the PTFE substrate by the accelerator and catalyst prior to the electroless itself. To ensure adequate electroless coverage, the substrate surface must be scrupulously clean, especially free from any oils and greases. Therefore, it is necessary to handle all parts with dry clean gloves between sodium etching and the onset of eletroless plating. For through-hole plating only, no special care was given to edge handling procedures. For example, when plating the MIL-P-55110 certification boards (IPC-B-25 Type Z, GR material), a normal electroless cycle was used after sodium etching. (See MP 742, Appendix D for processing procedures of electroless copper.)

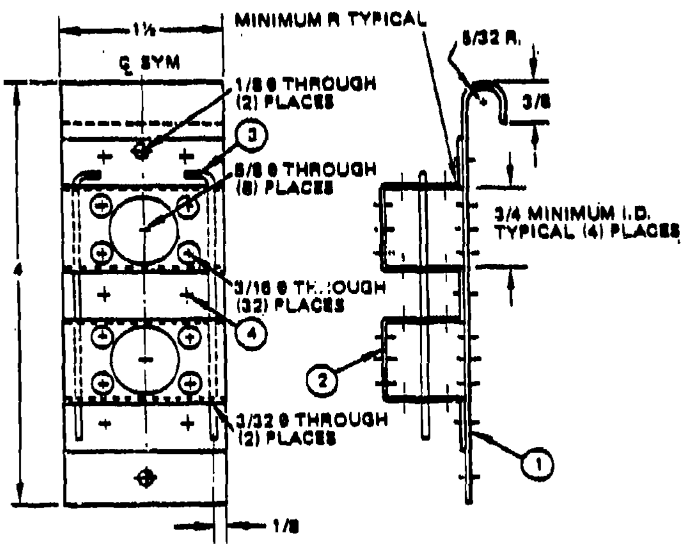
The 1 inch resonators that were developed for dielectric constant measurements required electroless copper shell plating only; however, it was mandatory that these parts were not bent. The average dielectric thickness to be plated was 0.007 inch, and a special plating fixture was developed to hold these thin agile squares (Figure 72). Once inside this special fixture, sodium etching and electroless copper deposition were conducted in a routine manner. The 3 dB quad presented an interesting shell plating technique. Since the side where the OSM connector areas are located were not to be shell plated, the parts were partially routed in panel form, and processed through electrolytic plating before being routed out of the panel. Sodium etching, followed by normal plating procedures, was all that was necessary to provide uniform shell and through hole plating.

The method of plating the IPC-B-25-GR and 3 dB quad shell plate required calculation of plating amperage. This was conducted using a Kahn area calculator. The appropriate amperage settings per panel are shown below:

PART	PANEL SIZE	AMPS COPPER	AMPS SOLDER
IPC-B-25	8 x 12 inches	25	22
3 dB Quad	8 x 12 inches	25	N/A

It can be concluded that conventional printed wiring board plating techniques can be used successfully for shell and through hole plating of Teflon substrate. (At the time of this report the IPC-B-25-GR passed in-house solder shock at 550°F for 10 seconds.) However, sodium etching must be conducted to provide adequate plating adhesion. Also, special plating fixtures may be required, as was demonstrated in the electroless shell plating of the 1 inch square resonators.

For a more detailed look at electrolytic plating start up processing, solution make up, and solution control procedures see Appendix E.



NOTES
1. IDENTIFY
2. HOLE LOCATIONS APPROX. AS SHOWN.
3. ALT: MAY BE SILVER SOLDERED.
4. BREAK ALL SHARP EDGES & CORNERS.

1	CRES. SHEET 0.020 X 1½ X 4-3/4	1 REQUIRED
2	CRES. SHEET 0.020 X 1½ X 6¾	1 REQUIRED
3	CRES. ROD 1/16 ⌀ X 2-3/4	2 REQUIRED
4	CRES. 'POP' RIVET, AS AVAILABLE 3	6 REQUIRED

Figure 72. 1 inch^2 Resonator Rack

SECTION XII
CONCLUSIONS AND RECOMMENDATIONS

The investigation of the sensitivity of strip transmission line tolerances on the performance of stripline circuits has shown some unexpected results. The broadband 3 dB quadrature coupler used as a model is much less sensitive to the dielectric constant of the material than is commonly assumed. The thickness of the centerboard, however, is very critical. The impression of the etched circuit into dielectric material also has the effect of decreasing the thickness of the centerboard. This impression is greatest at the overlapped center section of the coupler because of the extra thickness of the copper circuit. The effect is then a change in performance where the change is a function of frequency.

Other tolerances such as outer board thickness, circuit line widths, and the alignment of circuits on each side of the center board, are compatible with the processing of a printed wiring board facility, with good control of all processes. This requires precision measurement of resist photospeed to compensate for lot variations, a highly uniform intensity output of exposure units, and also feed and bleed chemical add systems to maintain bath chemistry. Alignment of photo tools and machining of the circuit boards is compatible with the CAD/CAM facility and numerically controlled machine tools.

Bonded and plated stripline assemblies showed good bonds and plating but poor electrical performance. The exact reason for this is assumed to be the impression of the circuit into the dielectric and perhaps the effect of the bonding material. Additional investigation of the bonding process is required.

The surface roughness of the copper cladding has been shown to have a large effect on the performance of the broadband couplers. An analysis showed that the effect is a function of the spacing between the rough surfaces. The effect of surface roughness was evident in the experimental data. A method of measuring the dielectric constant of small samples also showed the effect of the surface roughness.

A number of features can be incorporated into the stripline circuit designs to make them more producible and less susceptible to tolerances:

1) The thickness of the center board should be as large as possible.

2) Rolled copper, rather than electrodeposited copper, should be used if at all possible.

3) Thin copper cladding will reduce the impression of the circuit into the dielectric.

4) Do not overspecify the dielectric constant tolerance.

5) If there is more than one circuit that will perform the same function, pick the one that has fewer critical tolerances.

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APPENDIX A

EQUIPMENT LIST

APPENDIX A. EQUIPMENT LIST

EXIST. EQUIPMENT	I.D. NO.	OWNER	PROCURE COST	DATE PROCR'D
PUNCHING TOOL	I901046			
EXCELLON DRILL	H058495	HAC	113,515	9-72
EXCELLON DRILL	A752423	GOV'T.	115,074	2-75
EXCELLON DRILL	H059370	HAC	100,250	7-74
2 SPDC DRILL	T032290	GOV'T.	2,565	11-54
PRESSURE BLAST	T203513	GOV'T.	23,500	12-70
ELECTROLESS CU SYSTEM	T203521	GOV'T.	46,775	6-71
CHEM. CLEAN (ETCH BACK)	H-059737	HAC	4,789	3-75
CHEM-CUT SCRUBBER	H059435	HAC	9,975	7-74
LAMINATOR	H67320	HAC	8,450	8-77
LAMINATOR	H059702	HAC	4,007	2-75
PRINTER SCANEX	H058431	HAC	9,170	3-15-72
PRINTER PC-24	H34692	HAC	16,290	1-78
C-PROCESSOR	H057173	HAC	13,900	3-15-69
COPPER/SOLDER PLATE	T203514	GOV'T.	99,828	6-71
COPPER/SOLDER PLATE	A750900	GOV'T.	100,750	8-70
DUPONT RESIST STRIPPER	H067130	HAC	38,467	2-76
CHEM-CUT ETCHER	H059264	HAC	41,125	4-74
SOLDER FUSE	H059686	HAC	11,697	4-75
CLEANER	H59793	HAC	18,729	8-75
OVEN	T203505	GOV'T.	1,899	11-70
OVEN	T203506	GOV'T.	1,899	11-70
PUNCH PRESS	T031372	GOV'T.	3,143	7-54
ROUTER	H056540	HAC	3,911	12-67
CNC ROUTER EXCELLON	H67291	HAC	88,200	4-77
BEVELING MACHINE	H354900	HAC	3,323	9-70
AUTO SCAN TESTER	H59456	HAC	34,805	2-75

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APPENDIX A. (Continued)

PRESENT EQUIPMENT	I.D. NO.	OWNER	PROCURE COST	DATE PROCR'D
CAVIDERM	H59547	HAC	2,790	12-74
DERMITRON	H338386	HAC	1,213	12-75
TUKON MICROSCOPE AND HARDNESS TESTER	T029552	GOV'T.	4,237	3-53
PLOTTER	T203464	GOV'T.	19,195	9-67
CLEANER	H057630	HAC.	5,472	3-31-70
LAMINATING PRESS	T203508	GOV'T.	17,315	9-70
LAMINATING PRESS	H058285	HAC	17,135	10-28-71
MASKING MACHINE	H059652	HAC	7,950	2-30-75
STRIP SOLDER SYSTEM	NO NUMBER	HAC	3,000	6-75
NICKEL PLATE	H057620	HAC	1,830	2-5-70
GOLD PLATE	H058270	HAC	2,244	12-71
HAND SCRUB	T033904	GOV'T.	573	5-55
HAND SHEAR	H58463	HAC	576	6-72
LAMINATOR (RESIST)	H67370	HAC	8,450	3-77
COLD BOX (PREPREG)	H57559	HAC	820	6-70
DRY BOX	NO NUMBER	HAC	600	6-70
OVEN	H59420	HAC	2,148	6-17-74
HYDROSQUEEGEE	H59705	HAC	4,945	2-06-75
SLOTTER	040-01528	GOV'T.		
HI POT TESTER (2)	H311607	HAC	450	6-11-75
LIGHT TABLES (8)	H59807	HAC	1,800	60-75
ETCHER CHEM- UT	H59402	HAC	15,395	8-09-74
LOOSE FILM IXTURES (2)	035-71147	GOV'T.	14,000	'74
KODAK PROFILOMETER	T024092	GOV'T.	6,921	'64
FILM PROCESS SINKS	H58463	HAC	1,274	2-73
AUTO FILM PROCESSOR	H67142	HAC	17,781	'76
HYDRAULIC PREPREG PUSH-OUT PRESS	H58400	HAC	5,453	10-72
LIGHT SOURCE VACUUM FRAME AND TIMER	H57424	HAC	242	'69

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APPENDIX A. (Concluded)

NEW EQUIPMENT	I.D. NO.	OWNER	PROCURE COST	DATE PROCR'D
C. S. BAGGER	H354893	HAC	5,850	12-78
SCRUBBER	H354975	HAC	15,800	1-79
ETCHER	H354972	HAC	60,245	4-79
SOLDER MASK LAMINATOR	H354697	HAC	30,300	11-78
U. V. CURING EQUIPMENT	H354698	HAC	5,685	11-78
STILL METHYLENE CHLORIDE	H067130-10	HAC		2-76
STILL METHYL CHLOROFORM	H57872	HAC		
ALK FEED AND BLEED ETCHER	H59826	HAC		
VAPOR BLAST SYSTEM	H354976	HAC	27,800	5-79
LIGHT TABLE Y. R.	H59807			
LIGHT TABLE Y. R.	NO NUMBER			
LIGHT TABLE D. R.	NO NUMBER			
LIGHT TABLE D. R.	NO NUMBER			
LIGHT TABLE D. R.	H58259			
LIGHT TABLE DRILL INSP.	NO NUMBER			
LIGHT TABLE DRILL INSP.	NO NUMBER			
PROGRAMMER OPIC III	H354822			
STOCKEN & YALE	H353012			
X-RAY	H355225			
PLESSY-VISTA	FULLERTON H359003			
OHMEGAMETER	H354904			

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APPENDIX B

3 dB QUAD STRIPLINE CIRCUIT FABRICATION PROCEDURES

This appendix contains actual procedures used to fabricate the 3 dB quad stripline circuit in the production environment. It consists of five sections as listed below:

1) Outer Board No. 1
2) Outer Board No. 2
3) Inner Board
4) Prepreg (Bonding Film)
5) Board Assembly

Not only does this planning contain routing information and operator instructions but also a bar code. This bar code provides on-line, real-time quality history and parts status information. Utilizing a bar code wand, an operator enters the operation into a bar code terminal which then transmits the coded information to a main computer system for storage. This allows engineering access to material traceability, an interface with process monitoring and evaluation of process information.

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.OUTER#2 3DB QUAD OUTER #2

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (BUYOFFS)
5	NC	7742	6010	NONE	ENTER WORK ORDER QUANTITY. ________
10	NC	5154	9110	NONE	ISSUE CODE: UNKNOWN DESC.: .031" X 8" X 14" SPEC.: ORN-0290-C1/00-S2B PARTS PER PANEL = 6 :: HANDLE AS PACKAGED BY VENDOR PRODUCTION ________ ________ ________
20	NC	7744	6010	NONE	ISSUE & ENTER HAC LOT NUMBER LOT # ________ :: HANDLE IN CLEAN COVERED TOTE PAN PRODUCTION ________ ________ ________
43	NC	8531	0003	NONE	INSPECT PER PII & ITI QUALITY ________ ________ ________
100	NC	5581	2230	NONE	DRILL TOOLING HOLES (8" X 14") (CONTINUED)

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. OUTER#2 3DB QUAD OUTER #2

PLANNING REV. : NC DRAWING REV. : NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
100	NC	5581	2230	NONE	(CONTINUED) 95946 - DRILL JIG D36207 - 1/4" DRILL G-3465 - .250/.252" PLUG GAGE DRILL WITH COPPER SIDE UP. PRODUCTION ----------- ----------- -----------
330	NC	5581	2490	NONE	DRILL PER MP 317 & O.D. 330 (D/S) PRODUCTION ----------- ----------- -----------
333	NC	8531	0001	NONE	INSPECT DRILL - PII, ITI & O.D. 330 QUALITY ----------- ----------- ----------- QUALITY ----------- ----------- -----------
1000	NC	5581	4770	NONE	N/C ROUT PER MP 700 ROUT PER TOOLS & GAGES LISTINGS :: HANDLE SMALL "D" SHAPED PARTS IN A CLEAN ZIP-LOC PLASTIC BAG OBTAINED FROM STOCK. DO NOT BAG PANELS. (CONTINUED)

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.OUTER#2 3DB QUAD OUTER #2

PLANNING REV.:. NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
1000	NC	5581	4770	NONE	(CONTINUED) PLACE PANELS IN CLEAN TOTE PAN WITH CLEAN PAPER ON THE BOTTOM & BETWEEN LAYERS. PRODUCTION __________ __________ __________
1110	NC	5581	5340	NONE	FINAL CLEAN PER MP 739 :: AFTER FINAL CLEAN, BOARDS & TEST COUPONS ARE TO BE HANDLED BY THE EDGES ONLY OR WHEN WEARING CLEAN WHITE GLOVES. PRODUCTION __________ __________ __________
1120	NC	8531	0001	NONE	INSPECT PER PII & ITI QUALITY __________ __________ __________ QUALITY __________ __________ __________
1190	NC	7744	6080	NONE	PACKAGE & IDENTIFY PLACE PARTS IN A CLEAN TOTE PAN WITH CLEAN PAPER ON THE BOTTOM AND BETWEEN LAYERS. (CONTINUED)

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.OUTER#2 3DB QUAD OUTER #2

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
1190	NC	7744	6080	NONE	(CONTINUED) COMPLETE MATERIAL I.D. CARD WITH THE FOLLOWING INFORMATION: A. PART NUMBER & REVISION. B. WORK ORDER NO. C. QUANTITY D. DATE COMPLETED E. APPLICABLE CHANGE DOCUMENTS (EO'S, RDW'S, ETC.). IN THE REMARKS SECTION INSERT: 1. HAC MATERIAL LOT NO'S. 2. MASTER PATTERN REVISION FOR EACH LAYER. RETAIN MATERIAL I.D. TAG WITH TOTE PAN. PRODUCTION ---------- ---------- ----------
1260	NC	7718	9010	NONE	VERIFY & STORE ** INSPECT PER PII VERIFY COUNT & PACKAGING. COMPLETE PAPERWORK. RETAIN MATERIAL I.D. TAG WITH PARTS IN STORAGE. PRODUCTION ---------- ---------- ---------- QUALITY ---------- ---------- ----------

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED ************

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. OUTER#2 3DB QUAD OUTER #2

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

FABRICATION ORDER INFORMATION

PROCUREMENT CODE: ____________________

WORK ORDER QUANTITY: ____________________

QUANTITY REJECTED: ____________________

QUANTITY RECEIVED: ____________________

INPUT ____________ M-DAY ______________

SPLIT - TRANSFER TICKET - COUNT VARIANCE

OPERATION	SPLIT / TRANSFER TICKET	VARIANCE QUANTITY	BALANCE DELIVERED	M-DAY
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--------	-------------------------	--------	--------	--------

************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************

PRODUCTION PLANNING FOR: MMT.3DB.QUAD.OUTER#2 3DB QUAD OUTER #2

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 DATE PRINTED: 02/19/82 EFF.: P1-UP

PLANNER: C.E. WETENHALL P.A.E.: J.G. ROSSER P.E.: D.J. BROWNSTEIN

QUALITY LEVEL: EXP/PRG

NO OUTSTANDING DOCUMENTS

SPECIFICATIONS: HP 31-18 PROGRAM MMT UNIT CODE XXX

MATERIAL: .031" X 8" X 14" MATERIAL CODE: UNKNOWN

MATERIAL SPECIFICATIONS: GRN-0290-C1/00-B28

MASTER PATTERN: FRONT NUMBER NONE REV NONE
REAR NUMBER NONE REV NONE

PATTERN SET: NUMBER NONE

REFERENCE DRAWING NO. NONE

NO OUTSTANDING DOCUMENTS.

REASON FOR REVISION HISTORY - MMT.308.QUAD.OUTER#2 PAGE

REVISION NUMBER	REASON FOR REVISION	RELEASE DATE
NC	SAMPLE PLANNING FOR MMT DEVELOPMENT	

************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************

TOOL AND GAGES FOR P/N: MMT.3DB.QUAD.OUTER#2 3DB QUAD OUTER #2

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	TOOL OR GAGE NO.	DESCRIPTION
330	TOOLING HOLES 3DB.QUAD.OUTER#2/330	ONLY DRILL TAPE REV. NC
333	D.D. 330	DRILL LISTING
1000	PA-3DB.QUAD.OUTER#2 3DB.QUAD.OUTER#2	CONTOUR GUIDE ROUT TAPE REV. NC
1120	PA-3DB.QUAD.OUTER#2	CONTOUR GUIDE

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

OPERATIONAL INSTRUCTIONS: HMT.3DB.QUAD.OUTER#2 3DB QUAD OUTER #2 PAGE 1

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	OPER REV.	CONT CENT	WORK STA.	INSTRUCTIONS
330	NC	5581	2490	DRILL PER MP 317 & O.D. 330 (D/S)

DRILL SIZE/NO.	DRILL TOOL	HOLE SIZE	GAGE NUMBER	COLOR CODE	NO. OF HOLES
.1250 1/8"	D81250	124/127	G3369		4 NP

TOOLS AND GAGES:

NUMBER	DESCRIPTION
TOOLING HOLES	ONLY
3DB.QUAD.OUTER#2/330	DRILL TAPE REV. NC

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
5	NC	7742	6010	NONE	ENTER WORK ORDER QUANTITY. ------------------------------
10	NC	5154	9110	NONE	ISSUE CODE: UNKNOWN DESC.: .0077" X 8" X 14" SPEC.: QRN-0077-C1/C1-B2B PARTS PER PANEL = 6 :: HANDLE AS PACKAGED BY VENDOR PRODUCTION ---------- ---------- ----------
20	NC	7744	6010	NONE	ISSUE & ENTER HAC LOT NUMBER LOT # ------------------------------ :: HANDLE IN CLEAN COVERED TOTE PAN PRODUCTION ---------- ---------- ----------
43	NC	8531	0003	NONE	INSPECT PER PII & ITI QUALITY ---------- ---------- ----------
100	NC	5581	2230	NONE	DRILL TOOLING HOLES (8" X 14") (CONTINUED)

*************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
100	NC	5581	2230	NONE	(CONTINUED) 95946 - DRILL JIG D36207 - 1/4" DRILL G-3465 - .250/.252" PLUG GAGE PRODUCTION ----------- ----------- -----------
330	NC	5581	2490	NONE	N/C DRILL (INNERLAYERS) PER MP 317 PRODUCTION ----------- ----------- -----------
333	NC	8531	0001	NONE	INSPECT/DRILL PII, ITI (INNERLAYER) QUALITY ----------- ----------- ----------- QUALITY ----------- ----------- -----------
401	NC	5581	5960	NONE	SODIUM PERSULFATE ETCH (1) PASS ONLY THRU MODULE THEN SULFURIC-CITRIC ACID RINSE - 1 MINUTE WATER RINSE - 3 MINUTES DI WATER RINSE - 1 MINUTE AIR DRY. PRODUCTION ----------- ----------- -----------

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ********* ** QUAN *** DATE ***** STAMP ***
440	NC	5581	5965	NONE	RESIST LAMINATE PER MP 730 USE #1015 RESIST. :: COOL PANELS TO ROOM TEMPERATURE BEFORE PACKAGING. PRODUCTION ----------- ----------- -----------
450	NC	5581	7655	NONE	PHOTO RESIST EXPOSE PER MP 731 PATTERN SET: PA-92201-3DB. QUAD. INNER. 3NC MASTER PATTERN: T92201-1 REV. NC T92201-2 REV. NC PRODUCTION ----------- ----------- -----------
460	NC	5581	7650	NONE	PHOTO RESIST DEVELOP PER MP 732 :: RACK & AIR DRY PANELS BEFORE PACKAGING WITH CLEAN PAPER ON BOTTOM & BETWEEN LAYERS. PRODUCTION ----------- ----------- -----------
480	NC	8531	0003	NONE	INSPECT PER PII & ITI QUALITY ----------- ----------- ----------- QUALITY ----------- ----------- -----------

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ********* ** QUAN *** DATE ***** STAMP ***
580	NC	5581	5960	NONE	ETCH PER MP 735
					OBTAIN LAB REPORT ON ALKALINE ETCH SOLUTION BEFORE PROCESSING PARTS.
					QUALITY ECLR BUYOFF
					#--------------------
					PRODUCTION
					---------- ---------- ----------
					QUALITY
					---------- ---------- ----------
581	NC	5581	5960	NONE	INSPECT ETCH
					SHEAR TEST COUPON FROM PANEL
					* MEASURE UNDERCUT FROM EDGE OF RESIST TO EDGE OF CIRCUIT
					* MEASURE DIELECTRIC THICKNESS
					QUALITY
					---------- ---------- ----------
610	NC	5581	5355	NONE	STRIP RESIST PER MP 734
					PRODUCTION
					---------- ---------- ----------
1150	NC	8531	0003	NONE	FINAL INSPECT PER PII & ITI
					QUALITY ECLR BUYOFF

(CONTINUED)

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP	******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
1150	NC	8531	0003	NONE		(CONTINUED)

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QUALITY

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QUALITY

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OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP	
1190	NC	7744	6080	NONE		PACKAGE & IDENTIFY

PLACE PARTS IN A CLEAN TOTE PAN WITH CLEAN PAPER ON THE BOTTOM AND BETWEEN LAYERS.

COMPLETE MATERIAL I.D. CARD WITH THE FOLLOWING INFORMATION:

A. PART NUMBER & REVISION.
B. WORK ORDER NO.
C. QUANTITY
D. DATE COMPLETED
E. APPLICABLE CHANGE DOCUMENTS (EO'S, RDW'S, ETC.).

IN THE REMARKS SECTION INSERT:
1. HAC MATERIAL LOT NO'S.
2. MASTER PATTERN REVISION FOR EACH LAYER.

RETAIN MATERIAL I.D. TAG WITH TOTE PAN.

PRODUCTION

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************** UNRELEASED ***** UNRELEASED ***** UNRELEASED ************

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
1260	NC	7718	9010	NONE	VERIFY & STORE ** INSPECT PER PII VERIFY COUNT & PACKAGING. COMPLETE PAPERWORK. RETAIN MATERIAL I.D. TAG WITH PARTS IN STORAGE.

PRODUCTION

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QUALITY

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PRODUCTION ROUTING FOR: MMT.3DB.QUAD.INNER 3DB QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

FABRICATION ORDER INFORMATION

PROCUREMENT CODE: --------------------

WORK ORDER QUANTITY: -----------------

QUANTITY REJECTED: -------------------

QUANTITY RECEIVED: -------------------

INPUT ----------- M-DAY -------------

SPLIT - TRANSFER TICKET - COUNT VARIANCE

OPERATION	SPLIT / TRANSFER TICKET	VARIANCE QUANTITY	BALANCE DELIVERED	M-DAY
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************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************

PRODUCTION PLANNING FOR: MMT.308.QUAD.INNER 308 QUAD INNERLAYER PAGE 1

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 DATE PRINTED: 02/19/82 EFF.: P1-UP

PLANNER: C.E. WETENHALL P.A.E.: J.G. ROSSER P.E.: D.J. BROWNSTEIN

QUALITY LEVEL: EXP/PRG

NO OUTSTANDING DOCUMENTS

SPECIFICATIONS: HP 31-18 PROGRAM MMT UNIT CODE XXX

MATERIAL: .0077" X 8" X 14" MATERIAL CODE: UNKNOWN

MATERIAL SPECIFICATIONS: GRN-0077-C1/C1-828

MASTER PATTERN: FRONT NUMBER T92201-1 REV NC
REAR NUMBER T92201-2 REV NC

PATTERN SET: NUMBER PA-92201-308.QUAD.INNER.3NC

REFERENCE DRAWING NO. NONE

NO OUTSTANDING DOCUMENTS.

REASON FOR REVISION HISTORY - MMT.30B.QUAD.INNER PAGE

REVISION NUMBER	REASON FOR REVISION	RELEASE DATE
NC	SAMPLE PLANNING FOR MMT DEVELOPMENT	

************ UNRELEASED ***** UNRELEASED ***** UNRELEASED **************** PAGE 1

TOOL AND GAGES FOR P/N: MMT.308.QUAD.INNER 308 QUAD INNERLAYER

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	TOOL OR GAGE NO.	DESCRIPTION
330	308.QUAD.INNER	DRILL TAPE REV. NC
580	308.QUAD.INNERLAYER	1 OZ. COPPER
1150	A. PA-92201.308.I/L	PAE VISUAL AID
	A2 MASTER PATTERN	T92201-2 REV. NC
	A1 MASTER PATTERN	T92201-1 REV. NC

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED ************

OPERATIONAL INSTRUCTIONS: MMT.3DB.QUAD.INNER   3DB QUAD INNERLAYER

PLANNING REV.: NC   DRAWING REV.:   NC

PLANNING DATE: 12/22/81   PRINTED: 02/19/82   EFF.: P1-UP

OPER	OPER REV.	CONT CENT	WORK STA.	INSTRUCTIONS
330	NC	5581	2490	N/C DRILL (INNERLAYERS) PER MP 317

DRILL SIZE/NO.	DRILL TOOL	HOLE SIZE	GAGE NUMBER	COLOR CODE	NO. OF HOLES
.1250 1/8"	D81250	124/127	G3368		4 NP

TOOLS AND GAGES:

NUMBER	DESCRIPTION
3DB.QUAD.INNER	DRILL TAPE REV. NC

*************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT. 3DB. QU. P/P 3DB GUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP ***
5	NC	7742	6010	NONE	ENTER WORK ORDER QUANTITY. ________________
40	NC	5154	9110	NONE	ISSUE CODE: UNKNOWN SIZE: .0015" X 8" X 14" PARTS PER SHEET = 6 ENTER HAC LOT NUMBER # ________________ :: HANDLE IN CLEAN COVERED TOTE PAN THIS IS SHELF LIFE MATERIAL. SHELF LIFE LABEL MUST BE MAINTAINED WITH MATERIAL THRU TO STORES. PRODUCTION ________ ________ ________

PRODUCTION ROUTING FOR: MMT.3DB.QU.P/P 3DB QUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
55	NC	5581	6010	NONE	CUT TO SHEET SIZE PER W/O QUANTITY. ** INSPECT PII & ITI CODE IS: # UNKNOWN SIZE IS: .0015" X 8" X 14". PARTS PER SHEET = 6. ENTER HAC LOT NUMBER LOT # ---------------------------. :: PLACE MATERIAL IN A CLEAN COVERED TOTE PAN PRODUCTION ---------- ---------- ---------- QUALITY ---------- ---------- ----------
100	NC	5581	2230	NONE	DRILL TOOLING HOLES (8" X 14") 95946 - DRILL JIG D36207 - 1/4" DRILL G-3465 - .250/.252" PLUG GAGE TO DRILL PREPREG STACK AS LISTED: TOP BACK-UP BOARD ENTRY MATERIAL KODACEL PREPREG KODACEL PREPREG KODACEL ENTRY MATERIAL BACKUP BOARD BOTTOM PRODUCTION ---------- ---------- ----------

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT.3DB.QU.P/P 3DB QUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNED 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
330	NC	5581	2490	NONE	N/C DRILL (ACRYLIC PREPREG) PER MP 317 & O.D. 330 PRODUCTION ------------ ------------ ------------
1000	NC	5581	4770	NONE	N/C ROUT (ACRYLIC P/P) PER MP 700. PRODUCTION ------------ ------------ ------------
1100	NC	5581	6070	NONE	DEBURR ACRYLIC PREPREG PER MP 764 PRODUCTION ------------ ------------ ------------
1150	NC	8531	0003	NONE	FINAL INSPECT PER PII & ITI QUALITY ------------ ------------ ------------ QUALITY ------------ ------------ ------------
1190	NC	7744	6080	NONE	PACKAGE & IDENTIFY COMPLETE MATERIAL I.D. CARD WITH THE FOLLOWING INFORMATION: A. PART NUMBER & REVISION B. WORK ORDER NO. C. QUANTITY D. DATE COMPLETED (CONTINUED)

PRODUCTION ROUTING FOR: MMT.3DB.QU.P/P 3DB QUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
1190	NC	7744	6080	NONE	(CONTINUED) E. APPLICABLE E.O.'S IN THE REMARKS SECTION WRITE THE HAC PREPREG LOT NUMBER PLACE PARTS IN CLEAN PLASTIC BAG. INSERT MATERIAL I.D. TAG IN BAG, EXPEL EXCESS AIR AND SEAL. PRODUCTION ----------- ----------- -----------
1220	NC	7728	5541	NONE	VERIFY & STORE (ACRYLIC P/P) ** INSPECT PII & ITI STORE IN DRY BOX LOCATED IN ETCHED CIRCUITRY AT COL. B-9. ******* NOTE ******* SEND PAPERWORK TO CENTRAL STORES. PRODUCTION ----------- ----------- ----------- QUALITY ----------- ----------- -----------

PRODUCTION ROUTING FOR: MMT.3DB.QU.P/P 3DB QUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

FABRICATION ORDER INFORMATION

PROCUREMENT CODE: ----------------------

WORK ORDER QUANTITY: -------------------

QUANTITY REJECTED: ---------------------

QUANTITY RECEIVED: ---------------------

INPUT ------------ M-DAY --------------

SPLIT - TRANSFER TICKET - COUNT VARIANCE

OPERATION	SPLIT / TRANSFER TICKET	VARIANCE QUANTITY	BALANCE DELIVERED	M-DAY
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************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ************** PAGE 1

PRODUCTION PLANNING FOR: MMT.3DB.QU.P/P 3DB QUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 DATE PRINTED: 02/19/82 EFF.: P1-UP

PLANNER: C.E. WETENHALL P.A.E.: J.G. ROSSER P.E.: D.J. BROWNSTEIN

QUALITY LEVEL: EXP/PRG

NO OUTSTANDING DOCUMENTS

SPECIFICATIONS: HMS 16-1894 PROGRAM MMT UNIT CODE XXX

MATERIAL: .0015" X 8" X 14" MATERIAL CODE: UNKNOWN

MATERIAL SPECIFICATIONS: 3M 6700

MASTER PATTERN: FRONT NUMBER NONE REV NONE
REAR NUMBER NONE REV NONE

PATTERN SET: NUMBER NONE

REFERENCE DRAWING NO. NONE

NO OUTSTANDING DOCUMENTS.

REASON FOR REVISION HISTORY - MMT.308.QU.P/P

REVISION NUMBER	REASON FOR REVISION	RELEASE DATE
NC	SAMPLE PLANNING FOR MMT DEVELOPMENT	

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

OPERATIONAL INSTRUCTIONS: MMT.3DB.QU.P/P 3DB QUAD PREPREG

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	OPER REV.	CONT CENT	WORK STA.	INSTRUCTIONS
330	NC	5581	2490	N/C DRILL (ACRYLIC PREPREG) PER MP 317 & O.D. 330 & DRILL DATA LISTED BELOW:

DRILL SIZE/NO.	DRILL TOOL	HOLE SIZE	GAGE NUMBER	COLOR CODE	NO. OF HOLES
.1250 1/8"	D81250	124/127	G3368		4 NP

TOOLS AND GAGES:

NUMBER	DESCRIPTION
TOOLING HOLES	ONLY
MMT.3DB.QUAD.INNER	DRILL TAPE REV. NC

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************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************
                                                              PAGE   1
    TOOL AND GAGES FOR P/N:   MMT.30B.QU.P/P          30B QUAD PREPREG
    PLANNING REV.: NC      DRAWING REV.: NC
    PLANNING DATE: 12/22/81  PRINTED: 02/19/82  EFF.: P1-UP

    OPER     TOOL OR GAGE NO.        DESCRIPTION
    330            TOOLING HOLES   ONLY
               MMT.30B.QUAD.INNER    DRILL TAPE REV. NC
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************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP	******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
5	NC	7742	6010	NONE		ENTER WORK ORDER QUANTITY. _______________________________
30	NC	7718	9110	NONE		ISSUE INNERLAYER DETAILS LISTED IN TOOLS & GAGES PER WORK ORDER QUANTITY PARTS PER PANEL IS 6. ENTER HAC LOT NUMBER FOR EACH DETAIL. USE AS MANY LINES AS REQUIRED # _______________________________ # _______________________________ # _______________________________ # _______________________________ # _______________________________ # _______________________________ # _______________________________ # _______________________________ :: HANDLE IN CLEAN COVERD TOTE PAN PRODUCTION __________ __________ __________
43	NC	8531	0003	NONE		INSPECT PER PII & ITI QUALITY __________ __________ __________

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV. : NC DRAWING REV. : NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
120	NC	5573	7000	NONE	TETRA ETCH

** INSPECT
VERIFY EXPOSED SURFACE TO BE FLAT BLACK

PERFORM TETRA-ETCH OPERATION UNDER VENTED HOOD ONLY.

***** CAUTION *****
PROPER SAFETY EQUIPMENT MUST BE WORN.

USE A LONG SLEEVED SMOCK, FACE SHEILD AND NATURAL RUBBER GLOVES.

SEE YOUR SUPERVISOR FOR SAFETY EQUIPMENT.

DO NOT PROCESS PARTS WITHOUT A PROCESS ENGINEER PRESENT.

USE THE FOLLOWING PROCEEDURE:
USE PA 3938 TANK RACK.

FILL TANKS AS LISTED BELOW:
- TANK 1 - TETRA-ETCH (MRO5-0450)
- TANK 2 - CHLOROTHANE NU (MRO 5-0650)
- TANK 3 - CHLOROTHANE NU (MRO 5-0650)
- TANK 4 - ACETONE (MRO 5-0000)
- TANK 5 - ACETONE (MRO 5-0000)

********* CAUTION *********
PROPER SAFETY EQUIPMENT MUST BE WORN.

PROCESS PER LIST BELOW:
TANK 1 TETRA-ETCH - 2 MINUTES MIN.
TANK 2 CHLOROTHANE NU - 1 MINUTE MIN.
TANK 3-CHLOROTHANE NU - 1 MINUTE MIN.
TANK 4-ACETONE - 1 MINUTE MIN.
TANK 5-ACETONE - 1 MINUTE MIN.
AIR DRY

*************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
120	NC	5573	7000	NONE	(CONTINUED) OPERATOR: CHECK PANNELS 100%. THERE SHALL BE NO WAXY RESIDUE OR WHITE DEPOSITS ON THE SURFACE. IF THIS CONDITION IS FOUND, PERFORM THE PROCESS AGAIN. PRODUCTION ------------ ------------ ------------
155	NC	5581	5040	NONE	BOND PER MP 762 & MP 738 **INSPECT PI1 & ITI ENTER HAC PREPREG LOT NO. # ------------------------------ LAY-UP SEQUENCE & BONDED THICKNESS LISTED IN "TOOLS & GAGES" PRODUCTION ------------ ------------ ------------ QUALITY ------------ ------------ ------------
180	NC	5581	5960	NONE	SODIUM PERSULFATE ETCH (1) PASS ONLY THRU MODULE SULFURIC-CITRIC ACID RINSE - 1 MINUTE WATER RINSE - 1 MINUTE DI WATER RINSE - 1 MINUTE AIR DRY. PRODUCTION ------------ ------------ ------------

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
330	NC	5581	2490	NONE	DRILL PER MP 317 & O.D. 330 (M/L) X-RAY PER MP 769 PRODUCTION __________ __________ __________
333	NC	8531	0001	NONE	INSPECT DRILL - PII, ITI & O.D. 330 QUALITY __________ __________ __________ QUALITY __________ __________ __________
395	NC	5581	4770	NONE	N/C ROUT PER MP 700 ROUT PER TOOLS & GAGES LISTINGS :: PLACE KRAFT PAPER BETWEEN EACH LAYER OF BOARDS. PRODUCTION __________ __________ __________

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV. : NC DRAWING REV. : NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
396	NC	5581	6010	NONE	MASK PER O. D. 396 PRODUCTION ----------- ----------- ----------- QUALITY ----------- ----------- -----------
405	NC	5573	7000	NONE	TETRA ETCH ** INSPECT VERIFY EXPOSED SURFACE TO BE FLAT BLACK

PERFORM TETRA-ETCH OPERATION UNDER VENTED HOOD ONLY.

***** CAUTION *****
PROPER SAFETY EQUIPMENT MUST BE WORN.

USE A LONG SLEEVED SMOCK, FACE SHEILD AND NATURAL RUBBER GLOVES.

SEE YOUR SUPERVISOR FOR SAFETY EQUIPMENT.

DO NOT PROCESS PARTS WITHOUT A PROCESS ENGINEER PRESENT.

USE THE FOLLOWING PROCEEDURE:
USE PA 3938 TANK RACK.

FILL TANKS AS LISTED BELOW:
TANK 1 - TETRA-ETCH (MR05-0450)
TANK 2 - CHLOROTHANE NU (MRO 5-0650)
TANK 3 - CHLOROTHANE NU (MRO 5-0650)
TANK 4 - ACETONE (MRO 5-0000)
TANK 5 - ACETONE (MRO 5-0000) .

(CONTINUED)

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
405	NC	5573	7000	NONE	(CONTINUED)
410	NC	5581	5282	NONE	

(CONTINUED)
********* CAUTION *********
PROPER SAFETY EQUIPMENT MUST BE WORN.

PROCESS PER LIST BELOW:
TANK 1 TETRA-ETCH - 2 MINUTES MIN.
TANK 2 CHLOROTHANE NU - 1 MINUTE MIN.
TANK 3-CHLOROTHANE NU - 1 MINUTE MIN.
TANK 4-ACETONE - 1 MINUTE MIN.
TANK 5-ACETONE - 1 MINUTE MIN.
AIR DRY

OPERATOR: CHECK PANNELS 100%.
THERE SHALL BE NO WAXY RESIDUE OR WHITE DEPOSITS ON THE SURFACE.

IF THIS CONDITION IS FOUND, PERFORM THE PROCESS AGAIN.

PRODUCTION

__________ __________ __________

410 NC 5581 5282 NONE

ELECTROLESS COPPER SHELL PLATE PER MP 742
** INSPECT PII & ITI
VERIFY SHELL PLATE COMPLETE ON ALL EDGES

WEIGHT GAIN SAMPLE TO PROCESS CONTROL LAB REQUIRED EVERY 4 HOURS.

:: HANDLE BY EDGES ONLY, WEARING CLEAN, WHITE GLOVES.

QUALITY ECLR BUYOFF

(CONTINUED)

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED ************

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP ***
410	NC	5501	5282	NONE	(CONTINUED) PRODUCTION; QUALITY
490	NC	5581	5278	NONE	COPPER PLATE-ONLY PER MP 733 ** INSPECT PII & ITI. LAB SAMPLE REQUIRED. QUALITY ECLR BUYOFF; PRODUCTION; QUALITY

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
491	NC	5581	6010	NONE	REMOVE MASK
495	NC	5581	4770	NONE	N/C ROUT PER MP 700 ROUT PER TOOLS & GAGES LISTINGS

491 — REMOVE MASK

PRODUCTION

---------- ---------- ----------

QUALITY

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495 — N/C ROUT PER MP 700
ROUT PER TOOLS & GAGES LISTINGS

:: HANDLE PARTS IN CLEAN PLASTIC BAGS OBTAINED FROM STOCK OR IN CUSHIONED BAGS FROM MRO STORES.

BAGGED PARTS ARE TO BE PLACED FLAT IN A 25" X 17" X 3" CLEAN, COVERED TOTE PAN IN COMPARTMENTS FORMED BY A PLASTIC INSERT.

MAINTAIN THRU TO STORES.

IF PLASTIC INSERTS ARE NOT AVAILABLE, PLACE PAPER BETWEEN EACH LAYER OF BOARDS.

PRODUCTION

---------- ---------- ----------

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
750	NC	5581	7086	NONE	TRACEABILITY MARK MP 763 & OD 750 ** INSPECT PER ITI & OD 750 PRODUCTION ---------- ---------- ---------- QUALITY ---------- ---------- ----------
1110	NC	5581	5340	NONE	FINAL CLEAN PER MP 739 :: AFTER FINAL CLEAN, BOARDS & TEST COUPONS ARE TO BE HANDLED BY THE EDGES ONLY OR WHEN WEARING CLEAN WHITE GLOVES. OLD PLASTIC BAGS SHALL BE DISCARDED. PARTS SHALL BE REPACKAGED IN CLEAN PLASTIC BAGS. PRODUCTION ---------- ---------- ----------
1150	NC	8531	0003	NONE	FINAL INSPECT PER PII & ITI QUALITY ECLR BUYOFF ---------- ---------- ---------- QUALITY ---------- ---------- ---------- QUALITY ---------- ---------- ----------

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** E U Y O F F S ********)
1190	NC	7744	6080	NONE	IDENTIFY

COMPLETE MATERIAL I.D. CARD WITH THE FOLLOWING INFORMATION:

A. PART NUMBER & REVISION.
B. WORK ORDER NO.
C. QUANTITY
D. DATE COMPLETED
E. APPLICABLE CHANGE DOCUMENTS (EO'S, RDW'S, ETC.).

IN THE REMARKS SECTION INSERT HAC MATERIAL LOT NUMBER

RETAIN MATERIAL I.D. TAG WITH TOTE PAN.

PRODUCTION

__________ __________ __________

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	
1260	NC	7718	9010	NONE	VERIFY & STORE ** INSPECT PER PII

VERIFY COUNT & PACKAGING. COMPLETE PAPERWORK.

RETAIN MATERIAL I.D. TAG WITH PARTS IN STORAGE.

PRODUCTION

__________ __________ __________

QUALITY

__________ __________ __________

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. ASS'Y . 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

FABRICATION ORDER INFORMATION

PROCUREMENT CODE: --------------------

WORK ORDER QUANTITY: -----------------

QUANTITY REJECTED: -------------------

QUANTITY RECEIVED: -------------------

INPUT ------------ M-DAY --------------

SPLIT - TRANSFER TICKET - COUNT VARIANCE

OPERATION	SPLIT / TRANSFER TICKET	VARIANCE QUANTITY	BALANCE DELIVERED	M-DAY
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PRODUCTION PLANNING FOR: MMT.3DB.QUAD.ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 DATE PRINTED: 02/19/82 EFF.: P1-UP

PLANNER: C.E. WETENHALL P.A.E.: J.G. ROSSER P.E.: D.J. BROWNSTEIN

QUALITY LEVEL: EXP/PRG

NO OUTSTANDING DOCUMENTS

SPECIFICATIONS: HP 31-18 PROGRAM MMT UNIT CODE XXX

MATERIAL: STORES ITEMS MATERIAL CODE: AS ISSUED

MATERIAL SPECIFICATIONS: AS ISSUED

MASTER PATTERN: FRONT NUMBER NONE REV NONE
REAR NUMBER NONE REV NONE

PATTERN SET: NUMBER NONE

REFERENCE DRAWING NO. NONE

NO OUTSTANDING DOCUMENTS.

REASON FOR REVISION HISTORY - MMT.3DB.QUAD.ASS'Y

PAGE

REVISION NUMBER	REASON FOR REVISION	RELEASE DATE
NC	SAMPLE PLANNING FOR MMT DEVELOPMENT	

************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************

TOOL AND GAGES FOR P/N: 'MMT.3DB.QUAD.ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	TOOL OR GAGE NO.	DESCRIPTION
30	92201-A-GR 92201-B-GR 92201-C-GR 92201-D-PP	INNERLAYER OUTERLAYER #1 OUTERLAYER #2 PREPREG
155	A. TOP OF B. 92201-B-GR C. 92201-D-PP D. 92201-A-GR E. 92201-D-PP F. 92201-C-GR G. BOTTOM OF H. BONDED THICKNESS:	LAY-UP OUTERLAYER #1 PREPREG INNERLAYER PREPREG OUTERLAYER #2 LAY-UP .070/.075"
330	O.D. 330 PA-3DB.QUAD.ASS'Y-1NC 3DB.QUAD.ASS'Y/330	DRILL LISTING HOLE LOCATION GUIDE DRILL TAPE REV. NC
333	O.D. 330	DRILL LISTING
395	PA-3DB.QUAD.395-2NC 3DB.QUAD.ASS'Y/395	CONTOUR GUIDE ROUT TAPE REV. NC
396	O.D. 396	MASK
495	PA-3DB.QUAD.ASS'Y-2NC 3DB.QUAD.ASS'Y/495	CONTOUR GUIDE ROUT TAPE REV. NC
750	O.D. 750	TRACEABILITY MARK

OPERATIONAL INSTRUCTIONS: MMT.3DB.QUAD.ASS'Y 3DB QUAD ASS'Y

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	OPER REV.	CONT CENT	WORK STA.	INSTRUCTIONS
330	NC	5581	2490	DRILL PER MP 317 & O.D.330 (M/L) X-RAY PER MP 769

DRILL SIZE/NO.	DRILL TOOL	HOLE SIZE	GAGE NUMBER	COLOR CODE	NO. OF HOLES
.1259 3.20MM	D81259	124/127	G3368	RED	8 NP
.1440 #27	D91440	143/152	G14669	WHITE	8 NP

TOOLS AND GAGES:

NUMBER	DESCRIPTION
O.D. 330	DRILL LISTING
PA-3DB.QUAD.AS'Y-1NC	HOLE LOCATION GUIDE
3DB.QUAD.ASS'Y/330	DRILL TAPE REV. NC

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.OUTER#1 3DB QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S ********)
5	NC	7742	6010	NONE	ENTER WORK ORDER QUANTITY. ________________
10	NC	5154	9110	NONE	ISSUE CODE: UNKNOWN DESC.: .031" X 8" X 14" SPEC.: ORN-0290-C1/00-82B PARTS PER PANEL = 6 :: HANDLE AS PACKAGED BY VENDOR PRODUCTION ________ ________ ________
20	NC	7744	6010	NONE	ISSUE & ENTER HAC LOT NUMBER LOT # ________________ :: HANDLE IN CLEAN COVERED TOTE PAN PRODUCTION ________ ________ ________
43	NC	8531	0003	NONE	INSPECT PER PII & ITI QUALITY ________ ________ ________
100	NC	5581	2230	NONE	DRILL TOOLING HOLES (8" X 14") (CONTINUED)

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.OUTER#1 3DB QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (B U Y O F F S)
100	NC	5581	2230	NONE	(CONTINUED) 95946 - DRILL JIG D36207 - 1/4" DRILL G-3465 - .250/.252" PLUG GAGE DRILL WITH COPPER SIDE DOWN. PRODUCTION
330	NC	5581	2490	NONE	DRILL PER MP 317 & O.D. 330 (D/S) PRODUCTION
333	NC	8531	0001	NONE	INSPECT DRILL - PII, ITI & O.D. 330 QUALITY QUALITY
1000	NC	5581	4770	NONE	N/C ROUT PER MP 700 ROUT PER TOOLS & GAGES LISTINGS :: HANDLE PARTS IN CLEAN PLASTIC BAGS OBTAINED FROM STOCK OR IN CUSHIONED BAGS FROM MRO STORES. BAGGED PARTS ARE TO BE PLACED FLAT IN A 25" X 17" X 3" CLEAN, COVERED (CONTINUED)

PRODUCTION ROUTING FOR: MMT.3DB.QUAD.OUTER#1 3DB QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ******** B U Y O F F S ******** ** QUAN *** DATE ***** STAMP ***
1000	NC	5581	4770	NONE	(CONTINUED) TOTE PAN IN COMPARTMENTS FORMED BY A PLASTIC INSERT. MAINTAIN THRU TO STORES. IF PLASTIC INSERTS ARE NOT AVAILABLE, PLACE KRAFT PAPER BETWEEN EACH LAYER OF BOARDS. PRODUCTION __________ __________ __________
1110	NC	5581	5340	NONE	FINAL CLEAN PER MP 739 :: AFTER FINAL CLEAN, BOARDS & TEST COUPONS ARE TO BE HANDLED BY THE EDGES ONLY OR WHEN WEARING CLEAN WHITE GLOVES. PRODUCTION __________ __________ __________
1120	NC	8531	0001	NONE	INSPECT PER PII & ITI QUALITY __________ __________ __________ QUALITY __________ __________ __________
1190	NC	7744	4080	NONE	PACKAGE & IDENTIFY (CONTINUED)

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. OUTER#1 3DB QUAD OUTER #1

PLANNING REV. : NC DRAWING REV. : NC

PLANNED: 12/22/81 PRNTD: 02/19/82

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	SET UP ** QUAN *** DATE ***** STAMP *** (******** B U Y O F F S *********)
1190	NC	7744	6080	NONE	(CONTINUED)

PLACE PARTS IN A CLEAN TOTE PAN WITH CLEAN PAPER ON THE BOTTOM AND BETWEEN LAYERS.

COMPLETE MATERIAL I.D. CARD WITH THE FOLLOWING INFORMATION:

A. PART NUMBER & REVISION.
B. WORK ORDER NO.
C. QUANTITY
D. DATE COMPLETED
E. APPLICABLE CHANGE DOCUMENTS (EO'S, RDW'S, ETC.).

IN THE REMARKS SECTION INSERT:
1. HAC MATERIAL LOT NO'S.
2. MASTER PATTERN REVISION FOR EACH LAYER.

RETAIN MATERIAL I.D. TAG WITH TOTE PAN.

PRODUCTION

---------- ---------- ----------

OPER	OPER REV	CONT CENT	WORK STA.	STDS PER 100	
1260	NC	7718	9010	NONE	VERIFY & STORE

** INSPECT PER PII

VERIFY COUNT & PACKAGING.
COMPLETE PAPERWORK.

RETAIN MATERIAL I.D. TAG WITH PARTS IN STORAGE.

PRODUCTION

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QUALITY

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************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

PRODUCTION ROUTING FOR: MMT. 3DB. QUAD. OUTER#1 3DB QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNED: 12/22/81 PRNTD: 02/19/82

FABRICATION ORDER INFORMATION

PROCUREMENT CODE: ----------------------

WORK ORDER QUANTITY: ------------------

QUANTITY REJECTED: --------------------

QUANTITY RECEIVED: --------------------

INPUT ------------ M-DAY -------------

SPLIT - TRANSFER TICKET - COUNT VARIANCE

OPERATION	SPLIT / TRANSFER TICKET	VARIANCE QUANTITY	BALANCE DELIVERED	M-DAY
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************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************

PRODUCTION PLANNING FOR: MMT.3DB.QUAD.OUTER#1 3DB QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 DATE PRINTED: 02/19/82 EFF.: P1-UP

PLANNER: C.E. WETENHALL P.A.E.: J.G. ROSSER P.E.: D.J. BROWNSTEIN

QUALITY LEVEL: EXP/PRG

NO OUTSTANDING DOCUMENTS

SPECIFICATIONS: HP 31-18 PROGRAM MMT UNIT CODE XXX

MATERIAL: .031" X 8" X 14" MATERIAL CODE: UNKNOWN

MATERIAL SPECIFICATIONS: GRN-0290-C1/00-B28

MASTER PATTERN: FRONT NUMBER NONE REV NONE
REAR NUMBER NONE REV NONE

PATTERN SET: NUMBER NONE

REFERENCE DRAWING NO. NONE

NO OUTSTANDING DOCUMENTS.

REASON FOR REVISION HISTORY - MMT.3DB.QUAD.OUTER#1 PAGE

REVISION NUMBER	REASON FOR REVISION	RELEASE DATE
NC	SAMPLE PLANNING FOR MMT DEVELOPMENT	

************ UNRELEASED ***** UNRELEASED ***** UNRELEASED ***************

TOOL AND GAGES FOR P/N: MMT.3DB.QUAD.OUTER#1 3DB QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	TOOL OR GAGE NO.	DESCRIPTION
330	TOOLING HOLES 3DB.QUAD.OUTER#1/330	ONLY DRILL TAPE REV. NC
333	O.D. 330	DRILL LISTING
1000	PA-3DB.QUAD.OUTER#1 3DB.QUAD.OUTER#1	CONTOUR GUIDE ROUT TAPE REV. NC
1120	PA-3DB.QUAD.OUTER#1	CONTOUR GUIDE

************** UNRELEASED ***** UNRELEASED ***** UNRELEASED *************

OPERATIONAL INSTRUCTIONS: MMT.30B.QUAD.OUTER#1 30B QUAD OUTER #1

PLANNING REV.: NC DRAWING REV.: NC

PLANNING DATE: 12/22/81 PRINTED: 02/19/82 EFF.: P1-UP

OPER	OPER REV.	CONT CENT	WORK STA.	INSTRUCTIONS
330	NC	5581	2490	DRILL PER MP 317 & O.D. 330 (D/S)

DRILL SIZE/NO.	DRILL TOOL	HOLE SIZE	GAGE NUMBER	COLOR CODE	NO. OF HOLES
.1250 1/8"	D81250	124/127	G3368		4 NP

TOOLS AND GAGES:

NUMBER	DESCRIPTION
TOOLING HOLES	ONLY
30B.QUAD.OUTER#1/330	DRILL TAPE REV. NC

APPENDIX C

REPORT OF ANALYSIS OF ACCURACY AND REPEATABILITY OF EXCELLON DRILL MACHINES

OBJECTIVES OF ANALYSIS

1) Primary Objective: Determine expected accuracy and repeatability (consistency) of each Excellon drill machine with associated confidence limits.

2) Secondary Objective:

   - Develop a method for forecasting needed maintenance caused by wear and aging.
   - Develop a method of analysis which will define potential trouble areas that produce an assignable variance in product.
   - Determine if entry material has any significant effect on product variation.

METHODOLOGY

A PWB was designed that easily permitted isolation of deviations caused by machine axis and direction of travel. Each PWB has 60 drilled holes. Four boards are drilled simultaneously, one at each station on each of the three Excellon drill machines. Four runs are made on each machine, so that 16 total boards are drilled on each machine, giving us a total of 960 holes per machine.

An inspection program was written for the Cordax CMM which gave us a punched output of X and Y deviations from nominal hole positions. This punched output was then read in as a data file from each respective Excellon drill machine into the DTSS computer system.

Software was developed that sorted our input data base into 15 separate files. One of these files contains true position deviation from nominal. Manipulation of this file on each machine leads to these conclusions: (Numbers are ten-thousandths of an inch.)

	Average TP Deviation (Diameter)	σ
Machine 1 (East) H-58495	13.3319	5.5849
Machine 2 (West) H-59370	12.7146	5.4047
Machine 3 (North) A-752423	15.5523	5.5495

At the 3σ confidence level:

M1 30.0867

M2 28.9287

M3 32.2008

The probability of any machine drilling a hole with true position deviation greater than the 3σ level is 1.3499×10^{-3}.

At the 4σ confidence level:

M1 35.6715

M2 34.333

M3 37.7503

The probability as above, at the 4σ level is 3.1686×10^{-5}.

At the 5σ confidence level:

M1 41.2565

M2 39.7381

M3 43.2998

The probability at the 5σ level is 2.871×10^{-7}.

Further analysis of individual data files revealed that the individual axis deviation (not the true position, which is a composite of two separate axes) averaged around 4 (0.0004 inch). This number is uncomfortably close to the stated accuracy of the medium of inspection. Consequently, a further analysis to try to isolate deviation caused by the inspection procedure was implemented. Six boards having 360 holes were randomly selected from

machine 1. These boards were then reinspected, and this data file was compared to the original data file for the same boards. The average error caused by the inspection procedure is a TP deviation of 12.7307 ten thousandths with a σ of 5.174129. This is 80 to 100 percent of the total average error and 90 percent or more of the total variation. Ultraconservatively, it could be said that half of its average deviation measurement is caused by part variation and the other half is caused by measurement error. The same may be said for the variance. By the addition theorem of the normal distribution, the mean error may be subtracted directly from the total measured mean (being conservative, we will subtract only half of the error).

	$\bar{x}_T$	$\bar{x}_{E/2}$	$\bar{x}_p = \bar{x}_T - \bar{x}_{E/2}$	
M1	13.3319	6.3654	6.9665	$\bar{x}_p$ = part average
M2	12.7146	6.3654	6.3492	$\bar{x}_T$ = total average
M3	15.5523	6.3654	9.1869	$\bar{x}_E$ = error average

By the same law, the standard deviations may not be directly subtracted but the variances may.

$$\sigma_T^2 = \sigma_p^2 + \sigma_E^2 \Rightarrow \sigma_p^2 = \sigma_T^2 - \sigma_E^2 \Rightarrow \sigma_p = \sqrt{\sigma_T^2 - \sigma_E^2}$$

$$\text{if } \sigma_T^2 = 1/2\sigma_E^2 \text{ then } \sigma_p = \sqrt{\frac{\sigma_T^2}{2}} = \frac{1}{\sqrt{2}}\sigma_T$$

and

	σ_T	σ_p
M1	5.5849	3.9491
M2	5.4047	3.8217
M3	5.5495	3.9241

This leads us to the conclusion that the respective machines are capable of holding true position of:

Machine 1 $\bar{x}_p + 5\ \sigma_p = 6.9665 = 5^* \ 3.9491 = 26.712$

Machine 2 $\bar{x}_p + 5\ \sigma_p = 6.3492 + 5^* \ 3.8217 = 25.4577$

Machine 3 $\bar{x}_p + 5\ \sigma_p = 9.1869 + 5^* \ 3.9241 = 28.8074$

with a probability of 0.99999971.

At this point, that maximum material condition has never been taken into account in this analysis. If 0.004 at MMC were allowed, then all machines are capable of consistently holding true position zero.

It has been stated that entry material contributed to the accuracy of the excellon drill machines. A separate run was made (4 boards, 240 holes), and the data were run through an ANOVA (Analysis of Variance) program. The average difference in true position deviation due to entry material is 0.0000396 inch. The probability of entry material having any effect on positional accuracy of the drill machines is 0.08054.

While watching the drill machines at work, it was noticed that some of the pins used to located the PWBs on the machine table were easier to insert and remove than other pins. A simple test showed that some pins, and some bushings that received the pins, were worn. A separate run of the four boards was then made, using new (unworn) pins. Analysis of these data showed that new pins generated an improvement in positional accuracy of the X axis of approximately 0.0006 inch, but had virtually no effect on Y axis accuracy. It was later found that the top left bushing being used to hold the PWBs in place permitted the PWB to pivot in the X direction, but the lower right bushing prevented motion of the PWB in the Y direction.

CONCLUSIONS AND RECOMMENDATIONS:

1) Have all three Excellon drill machines defined as certified tools.

- Have the master check plate (PA3722) fitted with new bushings, and have two sets of new pins made for use with the check plate. The pins should be of two different (color coded) sizes. One size

(the larger pins) will be used as a flag for engineering evaluation of machine drift, and the smaller size will be used to certify machine accuracy at the beginning of each work day. The smaller pins and the check plate will then become part of the calibration recall system.

2) Develop control charts (range and X-bar) to track individual machine performance and to develop a model to predict machine drift.

3) Replace all bushings on all three machines (mounting bushings). Have a ring gage supplied to the Excellon area to check for pin wear periodically.

4) Discontinue design and fabrication of true position gages for PWBs if the true position tolerance required is greater than,or equal to, 0.004 or if the combined true position tolerance and MMC is greater than 0.004.

5) Do not eliminate other tests such as X-ray, overlay, etc.

NOTE: Data used in this analysis are on file at Fabrication Product Assurance Engineering (D/8500)

APPENDIX D

MANUFACTURING PROCEDURE
ELECTROLESS COPPER LINE, ETCHED CIRCUITRY

MANUFACTURING PROCEDURE

1. TITLE	2.
ELECTROLESS COPPER LINE, ETCHED CIRCUITRY	MP 742

5. REV. LTR.	DESCRIPTION	7. MADE BY	8. DATE
G	Changed Para's. 6.1.1, 6.6, 6.15, 6.16, 6.17, 7.2 and 7.4. Add Para's 5.5, 6.1.4, & 6.1.5	C. Pignato C. Pignato	6/18/80

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
	6-19-80		
14. PRODUCT ASSURANCE	15. DATE	16.	17. DATE
	-4-80		

1.0 Purpose:

1.1 To describe the operation of the Automated Electroless Copper Line, Line 4 Plating Shop.

2.0 Equipment:

2.1 The automatic card controlled system consists of twenty-three solution tanks plus a drying tank and loading area. (Also included are heat exchangers, controllers and pumps (T-203521). Located in Plating Shop).

3.0 Applicable Documents:

3.1 MP 309 pages 150 to 156 and page 216.

4.0 Materials:

4.1 See MP 309 pages 150 to 156 and page 216.

5.0 Operational Procedure, Preliminary Start-Up for Electroless Copper Tanks:

5.1 After any previous usage of the electroless copper tanks (Stations 24 or 25) they must be cleaned as follows:

5.1.1 Flush tank with water.

5.1.2 Fill tank with etching solution. (See Para. 10.1).

5.1.3 Circulate etching solution through heat exchanger and filteration systems until all evidence of copper plating is removed from the tank and pumping systems.

NOTE: If etching solution does not remove the copper plating from the tank after one (1) to two (2) hours of circulation, dump the solution and repeat the cleaning sequence from Para. 5.1.2.

5.1.4 Drain tank and flush the tank and heat exchanger thoroughly with water.

5.1.5 Fill tank with 5% sulfuric acid solution and circulate for a minimum of 15 minutes. (See Para. 10.2)

CONTROLLED COPY

5.1.6 Drain tank and flush tank, heat exchanger and filter system with deionized water.

5.2 Transfer the copper solution from the holding tank into the clean tank (Station 24 or 25).

5.3 Clean holding tank per Paragraph 5.1.

5.4 Bring operating tank to working level (MP 309 page 151) as follows

5.4.1 Start circulating bath through heat exchanger.

5.4.2 Increase temperature to 110°F.

5.4.3 Add 8 gallons of deionized water.

5.4.4 Add 1/2 gallon CP 70-A (to overflow side of weir).

5.4.5 Add 1 gallon CP-70-M.

5.4.6 Add 1/2 gallon CP 70-~~M~~ 2 9/1/80

5.4.7 If solution is still too low, repeat Steps 5.4.3 through 5.4.6.

5.5 The operator should make a color indicator check and make appropriate additions. (See MP 309, page 151).

5.5.1 Do not make additions to electroless tank with boards in tank.

5.6 Take a sample of mixed electroless copper solution to Process Control Lab. for analysis. Allow any additions to circulate a minimum of five (5) minutes before taking sample.

5.7 Skim any surface contaminants off all solutions/tanks before starting production.

5.8 All water rinse tanks shall be dumped and cleaned at the start of each production week (normally on Monday).

6.0 Start-Up Procedure:

6.1 Set the Partlow Temperature Controllers on the following stations at the temperature indicated.

6.1.1 Station Number 3 at 170°F.

6.1.2 Station Number 6 at 150°F.

6.1.3 Station Number 24 or 25 at 125°F.

6.1.4 Station Number 15 at 115°F.

6.1.5 Station Number 16 at 120°F.

6.2 The rinse tank controllers on Stations 3, 13, 19 and 21 must be on. These controllers function as on/off switches. Once per shift the operator must verify that water is flowing when the red indicator light is on. STATION 3 MUST BE OVERFLOWING AT ALL TIMES.

6.3 Place the "Auto-Off-Manual" switch on the master panel in the "Manual" position.

6.4 Depress "Manual Start" push button on master panel. The amber "Manual" light will come on.

6.5 Place "Auto-Off-Manual" switch on the hoist in the "Manual" position.

6.6 Place carriers in Stations 2, 4,7, 24 or 25, (5 optional).

6.7 Return hoist to the neutral position (between stations 4 and 5 with carrier arm in the down position). The hoist must be taken to station 3, then returned to neutral in order to activate the "Home Limit Switch."

6.8 Place "Auto-Off-Manual" switch on the hoist in the "Off" position.

6.9 Place "Auto-Off-Manual" switch on the master panel in the "Off" position.

6.10 Load program card in the reader on hoist panel as follows:

6.10.1 Depress square "Red" button on reader.

6.10.2 Slide card in from top until it engages thumb wheel.

6.10.3 Use thumb wheel (to right of glass window) to position card.

6.10.4 Place "Neutral" mark on card under hairline on glass window.

6.10.5 Depress square "Green" button on reader.

6.11 Depress "Mechanical Agitation Start" switch on master panel. Green light will come on.

6.12 Place "24 - Alternate - 25" selector switch in the appropriate position for the tank to be used.

6.13 Depress "dryer Start" switch. Green light will come on.

6.14 Place "Auto-Off-Manual" switch on hoist in "Auto" position.

6.15 Set timer T1 on hoist to 40 seconds.

MANUFACTURING PROCEDURE

1. TITLE	REV. LTR.	2.
ELECTROLESS COPPER LINE, ETCHED CIRCUITRY	G	MP 742

6.16 Set timer T2 on hoist to 120 seconds.

6.17 Set timer on master panel to 0 (zero) minutes.

6.18 Place "Auto-Off-Manual" switch on master panel in "Auto" position.

6.19 Depress "Auto Start" button. A green light will indicate automatic operation and another green light will indicate the electroless copper tank in use. (24 or 25).

7.0 Operation:

7.1 Load the carrier in Station #1 and continue to load and unload as necessary.

7.2 The work will progress through the system in the following sequence.

STATION	PROCESS	APPROXIMATE* TIME	SOLUTION (REF.)
1	Load	26 min.	
6	Cleaner	5 min.	MP 309, P. 156
7	Rinse	2 min.	Tap Water
8	Rinse	40 sec.	Tap Water
10	Etch	40 sec.	MP 309, p. 154
11	Rinse	40 sec.	D.I. Water
12	Rinse	40 sec.	D.I. Water
14	Acid (H_2SO_4)	2 min.	MP 309, p. 155
13	Rinse	40 sec.	D.I. Water
15	Pre-Dip	2 min.	MP 309, p. 153
16	Catalyst 44	4 min.	MP 309, p. 152
17	Rinse	2 min.	D.I. Water
18	Rinse	40 sec.	D.I. Water
19	Rinse	Dip	D.I. Water
20	Accelerator	5 min.	MP 309, p. 150
22	Rinse	Dip	D.I. Water
21	Rinse	2 min.	D.I. Water
24 or 25	Copper	26 min.	MP 309, p. 151
26	Rinse	2 min.	D.I. Water
23	Rinse	2 min.	D.I. Water
14	Acid (H_2SO_4) 39 TI	2 min.	MP 309, p. 155
13	Rinse HAC 0 T008	2 min.	D.I. Water
12	Rinse	90 sec.	D.I. Water
4	Acid (H_2SO_4) + ($C_6H_{10}O_4$)	3 min.	MP 309, p. 216
3	Rinse (Hot D.I.) 8/26/81	22 min.	must be over flowing
2	Dryer	17 min.	
1	Unload-Load	26 min.	

*Time depends on hoist movements.

7.3 The operator shall replenish the copper bath (Stations 24 or 25) according to MP 309, page 151.

7.4 The operator shall replenish the catalyst 44 bath according to MP 309, page 152.

8.0 Shut-Down Procedure:

8.1 After the workload has been removed from the copper tank, the tank should be treated as follows:

8.1.1 Turn off the steam.

8.1.2 After about five minutes turn on the cold water to the appropriate heat exchange system (Station 24 or 25, whichever was in use) to cool the copper solution.

8.1.3 Continue circulation through the cooling system for about an hour.

8.1.4 Transfer the solution to the other copper tank using only the filter pump for transfer. The tank being transferred into shall have been cleaned per Paragraph 5.1.

8.1.5 Clean the tank according to Paragraph 5.1.

8.2 After final workload has returned to Station #1, the following shut-down procedure should be followed:

8.2.1 Place "Auto-Off-Manual" switch on the master panel in the "Off" position.

8.2.2 Place "Auto-Off-Manual" switch on hoist in the "Off" position.

8.2.3 Depress "Mechanical Agitation Stop" button.

8.2.4 Depress "Dryer Stop" button.

8.2.5 Turn off the steam on Stations 3 and 6 by placing the Partlow Temperature Controllers on each tank at a setting of 50°F.

8.2.6 Turn off main switch on master panel.

9.0 Requirements:

9.1 The operator shall check one board from every rack processed for black holes. Black holes indicate lack of copper coverage and must be brought to the Foreman's attention.

9.2 The operator shall perform an adhesion test on one board from every rack processed. The test shall be done by placing a piece of three inch vinyl backed platers tape (MRO 52-2056), or equivalent, across the board and then sharply pulling the tape off. The operator shall inspect the tape and board for any copper pulled off.

9.3 The operator shall send one "weight gain" sample every 4 hrs. to the Process Control Lab. to verify that the copper thickness is greater than 50 millionths.

9.4 The operator shall submit a sample of Ammonium Persulfate to the Process Control Lab. as required per MP 309 page 154.

9.5 The operator shall submit an electroless copper solution sample to the Process Control Lab. as required per MP 309 page 151.

10.0 Chemical Solutions Needed for Cleaning Copper Tanks (Station 24 or 25):

10.1 Use the etching solution that is to be discarded from Station #10 (MP 309, page 154) whenever possible to clean the electroless copper tanks. (See Paragraph 5.1.2). If this solution is not available, make up an etching solution as follows:

10.1.1 Fill tank to be cleaned 3/4 full with water.

10.1.2 Add 45 lbs. of Ammonium Persulfate (MRO 5-0445).

10.1.3 Fill with water to within 4 inches of top of tank.

10.1.4 Circulate solution through heat exchanger and filtration systems. If the etching solution does not remove the copper plating from the tank after one (1) to two (2) hours, dump the solution and repeat the cleaning sequence from Paragraph 10.1.1.

10.2 Sulfuric acid cleaning solution.

10.2.1 Fill tank 3/4 full of water.

10.2.2 Carefully add 5 gallons of Sulfuric Acid (MRO 5-0210).

10.2.3 Fill with water to within 4 inches of top of tank.

10.2.4 Circulate solution through heat exchanger and filtration systems for a minimum of fifteen (15) minutes.

NOTE: Protective clothing must be worn to protect skin and eyes when making up solutions.

MANUFACTURING PROCEDURE

TITLE	MP 309
PROCESS SOLUTION, MAKEUP AND CONTROL	

REV NO	DESCRIPTION	MADE BY	DATE
2	Revised Para's. 6.153.1.1 and 6.153.1.3	D.J. Gaffery	7-01-73
PROCESS ENGINEERING	8/19		DATE
APPROVAL	DATE 8/19/73		DATE

6.153.1 Solution: Cleaner - Conditioner

6.153.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Station #6, Col. B-14

6.153.1.2 Tank Capacity: 60 Gallons

6.153.1.3 Makeup:

*9076 PTH Cleaner (MRO 52-1835)	2.0 Gal.
Water, Tap	Balance
Operating Temperature	150°F ± 10°F

Working Level - Two to eight inches from top of tank.

Fill tank 3/4 full with water. Add conditioner and bring solution up to operating level with water.

6.153.1.4 Analysis Frequency: None

6.153.1.5 Process Control Limit: None

6.153.1.6 Specification Limit: None

6.153.1.7 Renewal Frequency:

Renew solution every week.

The solution may be renewed at any time shorter than the normal renewal frequency when requested by Process Engineering.

*Product of MacDermid Co.

MANUFACTURING PROCEDURE

Red Line Copy 2/26/80 Joel Mundy

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1. TITLE			
PROCESS SOLUTION, MAKEUP AND CONTROL		MP	309
5. REV. NO.	DESCRIPTION	7. MADE BY	8. DATE
3	Revised Para. 6.151.1.1	D.J. Gaffery	6-30-7[illegible]
10. PROCESS ENGINEERING	8/19/5[illegible]		9. DATE
14. PRODUCT ASSURANCE	8/19/5[illegible]		17. DATE

6.151.1 Solution: Ammonium Persulfate - Etch

6.151.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Station #10, Col. B-14

6.151.1.2 Tank Capacity: 60 Gallons

6.151.1.3 Makeup:

Ammonium Persulfate (MRO 5-0445)	45 lbs.
Sulfuric Acid - 96% (MRO 5-0210)	9 lbs.
Water, Deionized	Balance
Operating Temperature	Room Temperature

Working Level - From top of overflow weir to two inches below top of weir.

Fill tank 1/2 full with deionized water. Add the ammonium persulfate while continuously stirring the solution. Carefully add the acid. Fill with deionized water to operating level. Stir the solution until all of the ammonium persulfate is dissolved.

6.151.1.4 Analysis Frequency: Immediately after each renewal per Para. 6.151.1.7.

6.151.1.5 Process Control Limit:

Ammonium Persulfate	11-12 oz./gal.
Sulfuric Acid	14-16 g/l

6.151.1.6 Specification Limit:

Ammonium Persulfate	10-13 oz/gal.
Sulfuric Acid	13-17 g/l

6.151.1.7 Renewal Frequency:

Renew the solution after twenty-four (24) work orders or eight (8) hours of use, whichever comes first. The operator will maintain a log of make-up and parts processed and have a laboratory check before using the solution.

The solution may be renewed at any time shorter than the normal renewal frequency when requested by Process Engineering.

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Joel Minsky 2/26/80

PROCESS SOLUTION, MAKEUP AND CONTROL

309/154

C	Revised Para. 6.151.1.1	D.J. Gaffery (signature) D.J. Gaffery	6-30-75

8/19/75

8/19/75

6.151.1 Solution: ~~Ammonium~~ Sodium Persulfate - Etch

6.151.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Station #10, Col. B-14

6.151.1.2 Tank Capacity: 60 Gallons

6.151.1.3 Makeup:

2/26/80 Joel Minsky

~~Ammonium~~ Sodium Persulfate (MRO 5-0445)	60 ~~45~~ lbs.
Sulfuric Acid - 96% (MRO 5-0210)	27 ~~9~~ lbs.
Water, Deionized	Balance
Operating Temperature	Room Temperature

Working Level - From top of overflow weir to two inches below top of weir.

Fill tank 1/2 full with deionized water. Add the ~~ammonium~~ sodium persulfate while continuously stirring the solution. Carefully add the acid. Fill with deionized water to operating level. Stir the solution until all of the ammonium persulfate is dissolved.

6.151.1.4 Analysis Frequency: Immediately after each renewal per Para. 6.151.1.7.

6.151.1.5 Process Control Limit:

~~Ammonium~~ Sodium Persulfate	~~11-12~~ 15-17 oz./gal.
Sulfuric Acid	~~14-16 g/l~~ 6-8oz/gal (by wt)

6.151.1.6 Specification Limit:

~~Ammonium~~ Sodium Persulfate	~~10-13~~ 13-20 oz/gal.
Sulfuric Acid	~~13-17 g/l~~ 5-9 oz/gal (by wt)

6.151.1.7 Renewal Frequency:

Renew the solution after twenty-four (24) work orders or eight (8) hours of use, whichever comes first. The operator will maintain a log of make-up and parts processed and have a laboratory check before using the solution.

The solution may be renewed at any time shorter than the normal renewal frequency when requested by Process Engineering.

MANUFACTURING PROCEDURE

PAGE 155 OF	
2. TITLE: PROCESS SOLUTION, MAKEUP AND CONTROL	3. MP 309/155

5. REV. LTR.	DESCRIPTION	7. MADE BY	8. DATE
F	Revise Para.'s 6.152.1.4 & 6.152.1.7	H.P. Koenig	1/5/79

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
[signature]	1/22/79		
14. PRODUCT ASSURANCE	15. DATE	16.	17. DATE
[signature]	1/19/79		

6.152.1 Solution: Acid, Sulfuric; Deoxidizer

6.152.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Station #14 (Col. B-14).

6.152.1.2 Tank Capacity: 60 Gallons

6.152.1.3 Makeup:

Sulfuric Acid - 96% (MRO 5-0210 or 5-0220)	6 Gal.
Water, Deionized	Balance
Operating Temperature	Room Temperature

Working Level . Top of overflow weir to 2" below top of overflow weir.

Fill tank 1/2 full with deionized water. Carefully and slowly add 6 gallons of sulfuric acid with continuous stirring. Then fill with deionized water to operating level. Stir thoroughly.

NOTE: Protective clothing must be worn to protect skin and eyes when making up solution.

6.152.1.4 Analysis Frequency: After make-up and after one week of use.

6.152.1.5 Process Control Limit: 150 g/l - 200 g/l sulfuric acid

6.152.1.6 Specification Limit: 100 g/l - 250 g/l sulfuric acid

6.152.1.7 Renewal Frequency:

Renew the solution every two weeks

The solution may be renewed at any time shorter than the normal renewal frequency when requested by Process Engineering.

MAC T-335 (REV.8-67)

MANUFACTURING PROCEDURE

3. TITLE	MP
PROCESS SOLUTION, MAKEUP AND CONTROL	309/153

5. REV. LTR.	DESCRIPTION	7. MADE BY	8. DATE
D	Revised Para's. 6.150.1, 6.150.1.3, 6.150.1.5, 6.150.1.6, and 6.150.1.7	J. Misinsky	2/26/8

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
14. PRODUCT ASSURANCE	15. DATE	16.	DATE
	3/21/80		

6.150.1 Solution: Pre-Cleaner

6.150.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line, T-203521, Station #15, Col. B-14

6.150.1.2 Tank Capacity: 60 Gallons

6.150.1.3 Makeup:

Cataprep 404 (MRO 5-1737)	135 lbs.
Water-Deionized	Balance
Operating Temperature	115°F

Working Level - From top of overflow weir to two inches below top of overflow weir

Fill tank 1/2 full with deionized water. Carefully and slowly add the Cataprep 404 with continuous stirring. Fill to operating level with deionized water. Stir thoroughly.

NOTE: Protective clothing must be worn to prote skin and eyes when making up solution.

6.150.1.4 Analysis Frequency: Every 48 hours of usage.

6.150.1.5 Process Control Limit: 1.152-1.167 sp. gr.

6.150.1.6 Specification Limit: 1.136-1.167 sp. gr.

6.150.1.7 Renewal

The bath will be renewed by request of Process Engineering only.

MAC T-395 (REV.5-67)

MANUFACTURING PROCEDURE

TITLE	PROCESS SOLUTION, MAKEUP AND CONTROL	PAGE 152 OF	MP 309/152

REV. LTR.	DESCRIPTION	MADE BY	DATE
C	Revised Para. 6.149.1.3, 6.149.1.5, 6.149.1.6, and 6.149.1.7. Deleted Para. 6.149.8	J. Misirmsky	2/26/80

PROCESS ENGINEERING	DATE 3/11/80			DATE
PRODUCT ASSURANCE	DATE 3/21/80			DATE

6.149.1 Solution: Catalyst

6.149.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Station #16, Col. B-14.

6.149.1.2 Tank Capacity: 60 Gallons

6.149.1.3 Makeup:

Cataprep 404 (MRO 5-1737)	135 lbs.
Cataposit 44 (MRO 5-1738)	2 gal.
Water	Balance

Operating Temperature 120°F

Working Level - From top of overflow to two inches below top of weir.

Fill tank 1/2 full with deionized water. Carefully add cataprep 404 and stir. Add Cataposit 44 while stirring the solution. Add deionized water to obtain operating level.

NOTE: Protective clothing must be worn to protect skin and eyes when making up solution.

6.149.1.4 Analysis Frequency: Weekly

6.149.1.5 Process Control Limits: 5.5-6.5 g/l $SnCl_2$

6.149.1.6 Specification Limits: 5.0-7.0 g/l $SnCl_2$

6.149.1.7 Replenishment:

The operator shall replenish the bath at the beginning of each week worked.

HAC ?-133 (REV.5-67)

MANUFACTURING PROCEDURE

1. TITLE	PROCESS SOLUTION, MAKEUP AND CONTROL		PAGE 151a OF MP 309/151
5. REV LTR	6. DESCRIPTION	7. MADE BY	8. DATE
F	Revised Paras. 6.148.1.3 and 6.148.1.7	D.J. Gaffery	6-20-77
10. PROCESS ENGINEERING	11. DATE 6/23/77	12.	13. DATE
14. PRODUCT ASSURANCE	15. DATE 6/23/77	16.	17. DATE

18.

6.148.1 Solution: Electroless Copper

6.148.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Stations #24 and #25 (Col. A-15).

6.148.1.2 Working Capacity: 90 Gallons

6.148.1.3 Makeup:

CP 70 - A *	MRO 5-1747	4.5 Gal.
CP 70 - M *	MRO 5-1748	9.0 Gal.
CP 70 - Z *	MRO 5-1750	4.5 Gal.
Water, Deionized		Balance
Operating Temperature		120°F ± 10°F

Working Level: The solution must be cascading over the weir and maintained from six to twenty inches above the bottom on the overflow side.

Fill the working side (large side) of the tank to within 6 inches from top of weir with deionized water. Start the water circulating through the heat exchanger and bring the temperature up to 110°F. Add CP-70-A and allow to circulate for 5 minutes. Add CP-70-M and allow to circulate for 5 minutes. Add deionized water until the solution cascades over the weir and is at a level 4 inches above the bottom on the overflow side. Add CP-70-Z and sufficient water to bring the solution level approximately half way up on the overflow side of the tank. (The solution should be cascading at this time).

6.148.1.4 Analysis Frequency: The solution must be checked at the beginning of each shift worked and every four hours during operation.

6.148.1.5 Process Control Limits:

1. Copper 1.7 to 2.2 grams per liter

   If the copper content is above the Process Control Limit it will plate down during operation

*Product of Shipley Co.

6.148.1.5 (cont'd)

2. Hydroxide 8 to 11 grams/liter

If the hydroxide is above the Process Control Limits the Process Control Lab. shall request the deletion of the appropriate number of normal additions of Cuposit Z (Ref. 6.148.1.7).

3. Formaldehyde 6.5 to 8.1 grams/liter

If the formaldehyde is above the Process Control Limits the Process Control Lab. shall request the deletion of the appropriate number of normal additions of CP-70-R (Ref. 6.148.1.7).

6.148.1.6 Specification Limits:

1. Copper 1.1 to 3.2 grams/liter
2. Hydroxide 6 to 17 grams/liter
3. Formaldehyde 4.5 to 14.0 grams/liter

6.148.1.7 Replenishment:

Normal replenishment to the bath will be made by the operator as required to maintain the bath within 80% to 100% copper content, according to the following procedure.

1. Place 55 ml. of copper mix color indicator (MRO # 5-1751) in a sample bottle.
2. Pipette 10 ml. of copper bath into the sample bottle.
3. Shake well.
4. Determine copper concentrate by comparison to color standard.
5. Replenish the bath according to the following table and in the sequence shown. The bath shall be held within working limits of 80% to 100%.

Replenishments for 90 Gal. Bath

% Copper	CP 70 M	CP 70 R *	CO 70 A	Cuposit Z
100	None	None	None	None
90	360 ml	900 ml	1800 ml	900 ml
80	720 ml	1800 ml	3600 ml	1800 ml
70	1080 ml	2700 ml	5400 ml	2700 ml

6. The operator shall maintain a log of all additions made. Never make an addition which will increase the relative copper concentration more than 20%.

* CP-70 R MRO # 5-1749

6.148.1.8 Renewal Frequency: The bath shall be renewed when requested by Process Engineering.

MANUFACTURING PROCEDURE

4. TITLE	PAGE 216 OF
PROCESS SOLUTION, MAKEUP AND CONTROL	MP - 300/216

5. REV LTR.	DESCRIPTION	7. MADE BY	8. DATE
C	Changed Para. 6.152.1.3	C. Pignato	6/13/80

12. PROCESS ENGINEERING	11. DATE	15.	14. DATE
	7-9-80		
14. PRODUCT ASSURANCE	13. DATE	16.	17. DATE
	7/7/80		

6.152.1 Solution: Acid, Sulfuric; Deoxidizer

6.152.1.1 Location: Plating Shop Line 4, Automated Electroless Copper Line T-203521, Station #4 (Col. B-14)

6.152.1.2 Tank Capacity: 60 Gallons

6.152.1.3 Makeup:

Sulfuric Acid - 96% (MRO 5-0210 or 5-0220)	1 Bottle (9 lbs)
CITRIC ACID 24 LBS (MRO 5-0092) 8/20/81	
Water, Deionized	Balance
Operating Temperature	Room Temperature

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Work Level: Top of overflow weir to 2" below top of overflow weir.

Fill tank 1/2 full with deionized water. Carefully and slowly, add one bottles of sulfuric acid with continuous stirring. Then fill with deionized water to operating level. Stir thoroughly.

NOTE: Protective clothing must be worn to protect skin and eyes when making up solution.

6.152.1.4 Analysis Frequency: None

6.152.1.5 Process Control Limit: None

6.152.1.6 Specification Limit: None

6.152.1.7 Renewal Frequency: Renew the solution ~~daily prior to use~~. MONDAY AND WEDNESDAY OF EACH WEEK.

39 8/20/81

The solution may be renewed at any time shorter than the normal renewal frequency when requested by Process Engineering.

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APPENDIX E

MANUFACTURING PROCEDURE
AUTOMATIC COPPER/SOLDER PLATING, ETCH CIRCUITRY

MANUFACTURING PROCEDURE

3. TITLE	MP 733-A
AUTOMATIC COPPER/SOLDER PLATING ETCHED CIRCUITRY	

5. REV. LTR.	DESCRIPTION	7. MADE BY	8. DATE
I	TOTAL REVISION	Paul W. Fecsik P.W. FECSIK	11-13-81

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
	12-2-81		
PRODUCT ASSURANCE	15. DATE	16.	17. DATE
	12-29-81		

1.0 Scope:

1.1 To describe the operation of the automatic copper/solder plating line T-203514 located in Building 801. north line of the Etched Circuitry Department.

2.0 Applicable Documents:

2.1 MP 309 Process Soltuions, Makeup and Control (pages 157 through 161, 218 and 219).

3.0 Equipment and Solutions:

3.1 The automatic copper/solder plating line consists of the following in-line equipment:

3.1.1 Station 1 - Load and unload stands.

3.1.2 Station 2 - Drier

3.1.3 Station 3 - Hot deionized water rinse with air agitation, MP 309, page 95, (Temperature 150°F ± 10°F).

3.1.4 Stations 4 and 5 - Solder plate tank with filter system, auxiliary carbon treatment chamber and rectifier, MP 309, page 160.

3.1.5 Station 6 - 20% fluoboric acid pickle tank, MP 309, page 219.

3.1.6 Station 7 - Deionized water rinse tank with air agitation, MP 309, page, 95.

3.1.7 Station 8 - 10% fluoboric acid pickle tank, MP 309, page 158.

3.1.8 Station 9 - Alkaline cleaner tank, MP 309, page 157. (Temperature 135°F ± 10°F).

3.1.9 Station 10 - Overflowing water rinse tank with air agitation and spray rinse.

3.1.10 Station 11 - Transfer water rinse tank.

3.1.11 Station 12 - Copper etch clean tank, MP 309, page 161.

3.1.12 Station 13 - Water rinse tank with air agitation and spray rinse.

3.1.13 Station 14 - Sulfuric acid deoxidizer tank, MP 309, page 159.

3.1.14 Station 15 - Deionized water rinse tank with air agitation and spray rinse, MP 309, page 95.

3.1.15 Station 16, 17, 18, 19, 21, 22, 23 and 24 - Four copper plating tanks with mechanical and air agitation, eight rectifiers, four filter pumps, auxiliary carbon treatment chambers, MP 309, page 218. (Temperature 75°F ± 5°F).

3.1.16 Station 20 - Deionized water rinse tank with air agitation and spray rinse, MP 309, page 95.

3.1.17 Other equipment consists of two automatic card programmed hoists with central control panel.

4.0 Start-up Procedure:

4.1 All electrical contact areas must be cleaned using Scotch Bright abrasive pads or equivalent.

4.1.1 The anode bars must be clean and free of dried salts. Anodes are to be slightly pushed back and forth across anode bars two times.

4.1.2 The saddles on Stations 4, 5, 16, 17, 18, 19, 21, 22, 23, and 24 must be cleaned at the initial start-up of the equipment and once every 24 hours during continuous operation. Both the bottom and sides of the saddles must be clean and free from dried salts.

4.1.3 The carriers must be cleaned in four areas:

4.1.3.1 The two contact knives which fit the saddles must be cleaned at the initial start-up of the equipment and once every 24 hours during continuous operation. Both the bottom and sides of these bars must be clean and free from dried salts.

4.1.3.2 The areas where the racks make contact to the carrier must be cleaned prior to each rack being loaded onto the carrier.

4.1.4 Each rack must be cleaned in two areas prior to each usage.

4.1.4.1 The contact points where the rack mates with the carrier must be cleaned prior to attaching to the carrier.

4.1.4.2 The copper and solder nodules must be removed from the screw clamps which hold the boards to the racks prior to each loading of boards.

4.1.5 Dummy copper baths for a normal 54 minute automatic plating cycle prior to processing parts after a minimum 48 hour shutdown. (See paragraph 7.3).

4.2 The solutions must be at the proper temperatures and within the appropriate limits per MP 309 or as specified by Process Engineer'.g.

4.2.1 Set the following Partlow Temperature Controllers at the indicated temperatures:

Station 3	150°F ± 10°F
Station 9	135°F ± 10°F
Station 16-17	75°F ± 5°F
Station 18-19	75°F ± 5°F
Station 21-22	75°F ± 5°F
Station 23-24	75°F ± 5°F

4.3 Turn on air agitation for rinse tanks 3, 7, 10, 13, 15, and 20.

4.4 On both carrier panels set "Auto-Off-Manual" switch to "Off".

4.5 On Master Control panel:

4.5.1 Push the "Stop" button that corresponds to the "Manual-Start" button.

4.5.2 Turn "Master Switch" to on.

4.5.3 Turn key to "Manual" and depress "Manual Start" push button. Amber light will come on.

4.6 Position "Auto-Off-Manual" switch on both hoist panels to "Manual".

4.7 Flight bars should be positioned as required by program to be used (see paragraph 5.3). With carrier in "Manual" mode use "Joy Stick" to position flight bars.

4.8 Run carrier No. 2 to Station No. 20 to activate switch on rail. Then run back to neutral position with arm in appropriate position being used. (Neutral is defined for each program in paragraph 5.3).

4.9 Position Carrier No. 1 in neutral position (between Stations 1 and 2). Set arm in down position.

4.10 Insert appropriate program card in reader on both carriers as follows:

4.10.1 Depress square "Red" button on reader.

4.10.2 Slide card in from top until it engages thumb wheel.

4.10.3 Use thumb whell to position card.

4.10.4 Place "Neutral" mark on card under hairline on glass window.

4.10.5 Depress square "Green" button on reader and rotate thumb wheel to "Lock In" position at "Neutral". Check to see if "Neutral" is under hairline.

4.11 Set timer on Master Control Panel and T_1 and T_2 timers on carriers to program requirements. (See Paragraph 5.3).

4.12 Position program indicator on Carrier No. 1 to P1, P2, or P3 for program being used. Use P1 indication for any program number above 3. Indicator lights on top of control panel will indicate which program is being used.

4.13 When carriers are in position and ready to start, stop the machine by depressing "Stop" button on master panel.

4.14 Turn key "Off" on Master Control panel.

4.15 Turn Auto-Off-Manual switch on Carriers No. 1 and No. 2 to "Auto" position.

4.16 Turn key on Master Control Panel to "Auto" position.

4.17 Depress "Reset" button on Master Control Panel.

4.18 Depress "Auto" start push button on Master Control Panel. Green "Auto" light will come on master panel. Machine is now in automatic operation.

4.19 Depress "Drier" button on Master Control Panel to start drier.

4.20 Start rectifiers as follows:

4.20.1 Depress start push button for cooling on rectifier control panel. Cooling must be on before rectifiers can be started.

4.20.2 Set rectifier controls as follows:

4.20.2.1 Set Automatic Voltage Control knob and Constant Current Control knob to midway settings (12 o'clock position).

4.20.2.2 As parts enter plating bath, adjust Automatic Voltage Control knob so that current reading as shown on the A.C. input meter is at setting called out in plating amperage log. The Constant Current Control knob may require small adjustment to attain and maintain the desired amperage setting.

4.20.2.3 After rectifier has been set, plater will verify equal distribution of current on racks by use of a millivolt meter. Place one meter lead on cathode bus and then place other lead to flight bars then to left rack then to right rack. Voltage drop shall not exceed 20mV. If greater than 20mV drop, adjust flight bar on saddle and tighten rack wing nuts to lower readings.

5.0 Operation:

5.1 Load the carrier in Station 1 and continue to load and unload as necessary.

5.2 Each time a carrier is loaded the two "black" water push buttons on the Master Control Panel must be depressed. These flush rinse tanks 10, 13, and 20.

5.3 The work will progress through the plating line in the following sequence:

5.3.1 Program #1 Copper/Solder Plate:

5.3.1.1 Set master clock on Master Control Panel at 6.5 minutes or as specified on planning.

5.3.1.2 Flight bars will be located at Station 1, 2, 4, 5, 7, 10, 12, 16-19, 21-24 and Carrier #2.

5.3.1.3 Neutral position for Carrier #2 is defined as between Stations 11 and 12 with arm in the up position.

5.3.1.4 Set the Timers on the Carriers as follows:

Carrier #1	Timer #1	35 seconds
Carrier #1	Timer #2	0 seconds
Carrier #2	Timer #1	45 seconds
Carrier #2	Timer #2	30 seconds

5.3.1.5 Verify cams inside Master Control Console are set per Figure #1.

5.3.1.6 Use program cards labeled SC-48 using appropriate card for each hoist.

5.3.1.7 Mechanical agitation must be "On".

5.3.1.8 Program Sequence:

STEP	STATION	OPERATION	AUTOMATIC TIME (Depending on carrier speeds and Master Clock setting).
1	1	Load	30 seconds
2	9	Alkaline Clean	2 minutes, 4 seconds
3	10	Hot Rinse (transfer point)	4 minutes, 15 seconds
4	12	Etch	33 seconds, (Timer #1, Carrier #2)
5	13	Rinse	2 minutes, 57 seconds (Timer #1, Carrier #2)
6	14	Acid, Sulfuric	2 minutes, 56 seconds
7	15	Rinse	1 minute, 20 seconds (Timer #1, Carrier #2)

5.3.1.8 Program Sequence: (Continued)

STEP	STATION	OPERATION	APPROXIMATE TIME
8	16, 17, 18 19, 21, 22, 23, 24	Copper Plate	53 minutes
9	20	Rinse	1 minute, 34 seconds
10	12	Etch	30 seconds (Timer #1, Carrier #2)
11	13	Rinse	45 seconds (Timer #1, Carrier #2)
12	11	Transfer Rinse	
13	8	Fluoboric Acid	2 minutes, 15 seconds
14	7	Rinse	2 minutes, 19 seconds
15	6	Acid, Fluoboric	33 seconds
16	4 or 5	Solder Plate	13 minutes
17	7	Rinse	2 minutes
18	3	Rinse	30 seconds (Timer #2, Carrier #1)
19	2	Drier	2½ minutes
20	1	Unload	

5.3.2 Program 2, Copper Plate

5.3.2.1 Set master clock on Master Control Panel at 8 minutes or as specified in planning.

5.3.2.2 Flight bars will be located at Stations 1, 2, 4, 5, 10, 16, 17, 18, 19, 21, 22, 23, 24, and on Carrier #2.

5.3.2.3 Neutral position for Carrier #2 is defined as between Stations 11 and 12 with arm in the up position.

5.3.2.4 Set timers on carriers as follows:

Carrier #1	Timer #1	10 seconds
Carrier #1	Timer #2	30 seconds
Carrier #2	Timer #1	30 seconds
Carrier #2	Timer #2	60 seconds

5.3.2.5 Verify cams inside Master Control Console are set per Figure 1.

5.3.2.6 Use program cards as follows:

Program #2	Copper Plate
Carrier #1	Card #5
Carrier #2	Card #6

5.3.2.7 Mechanical agitation must be "On".

MANUFACTURING PROCEDURE

TITLE	REV. LTR.	MP
AUTOMATIC COPPER/SOLDER PLATING, ETCHED CIRCUITRY	I	733-A

5.3.2.8 Program Sequence:

STEP	STATION	OPERATION	TIME APPROXIMATE (Depending on carrier speeds and master clock setting)
1	1	Load	6½ minutes
2	9	Alk. Clean	1 minute
3	10	Rinse (Transfer Point)	5 minutes
4	12	Etch	30 sec. (Timer #1, Car. #2)
5	13	Rinse	60 sec. (Timer #1, Car. #2)
6	14	Acid, Sulfuric	60 sec.
7	15	Rinse	30 sec. (Timer #1, Car. #2)
8	(16,17) (18,19) (21,22) (23,24)	Copper Plate	65 minutes
9	20	Rinse	60 sec.
10	11	Rinse, Transfer Point	
11	8	Acid, Sulfuric	1 minute
12	7	Rinse	Double Dip
13	3	Rinse	30 sec. (Timer #2, Car. #1)
14	2	Drier	6½ minutes
15	1	Unload	

5.3.3 Program 3 Solder Plate

5.3.3.1 Set master clock on Master Control Panel at 7 min. or as specified in planning.

5.3.3.2 Flight bars will be located at Stations 1, 2, 4, 5, 10, 13, 16, 17, 18, 19, 21, 22, 23, 24.

5.3.3.3 Neutral position for Carrier #2 is defined as between Stations 11 and 12 with arm in the down position.

5.3.3.4 Set timers on carriers as follows:

Carrier #1	Timer #1	10 sec.
Carrier #1	Timer #2	30 sec.
Carrier #2	Timer #1	10 sec.
Carrier #2	Timer #2	30 sec.

5.3.3.5 Verify cams inside Master Control Console are set per Figure #1.

5.3.3.6 Use the following program cards:

Carrier #1	Card #1
Carrier #2	Card #3

5.3.3.6 (Continued)

STEP	STATION	OPERATION	TIME APPROXIMATE (Depending on carrier speeds and master clock setting)
1	1	Load	6½ minutes
2	9	Alk. Clean	2 minutes
3	10	Rinse Transfer Point	
4	12	Etch	30 sec. (Timer #2, Car. #2)
5	13	Rinse	60 sec.
6	11	Rinse Transfer Point	
7	8	Acid, Fluoboric	2 minutes
8	7	Rinse	Double Dip
9	6	Acid, Fluoboric	60 sec.
10	4 or 5	Solder Plate	13 minutes
11	7	Rinse	30 sec. (Timer #2, Car. #1)
12	3	Rinse	30 sec. (Timer #2, Car. #1)
13	2	Drier	6½ minutes
14	1	Unload	

5.3.4 Program 4 Copper Flash

5.3.4.1 Set master clock on Master Control Panel at 4 min. or as specified in planning.

5.3.4.2 Flight bars will be located at Stations 1, 2, 4, 5, 10, 16, 17, 18, 19, 21, 22, 23, 24, and on Carrier #2.

5.3.4.3 Neutral position for Carrier #2 is defined as between Stations 11 and 12 with the arm in the up position.

5.3.4.4 Set timers on carriers as follows:

Carrier #1	Timer #1	10 sec.
Carrier #1	Timer #2	10 sec.
Carrier #2	Timer #1	10 sec.
Carrier #2	Timer #2	15 sec.

5.3.4.5 Verify cams inside Master Console are set per Figure 2.

5.3.4.6 Use program cards as follows:

Carrier #1	Card #7	
Carrier #2	Card #8 or Card #9	(Tanks 16,17; 18,19) - #8
		(Tanks 21,22; 23,24) - #9

5.3.4.7 Mechanical agitation must be "On".

5.3.4.8 Program Sequence

STEP	STATION	OPERATION	TIME APPROXIMATE (Depending on carrier speed and master clock setting)
1	1	Load	4 minutes
2	9	Alk. Clean	1 minute
3	10	Hot Rinse (Transfer Point)	2 minutes
4	12	Etch	10 sec. (Timer #1, Car #2)
5	14	Acid, Sulfuric	1 minute
6	15	Rinse	1 minute
7	(16,17; 18,19) (21,22; 23,24)	Copper Flash	14 minutes
8	20	Rinse	10 sec. (Timer #1, Car.#2)
9	14	Acid, Sulfuric	1 minute
10	13	Rinse	15 sec. (Timer #2, Car.#2)
11	11	Rinse (Transfer Point)	2 minutes
12	3	Hot Rinse	1 minute
13	2	Drier	2 minutes
14	1	Unload	

5.4 Emergency Stop:

Both carriers have an "OFF" position on control panel. The Master Control Panel has a red stop push button. Also, a pull line cord emergency stop runs along entire length of machine. Pulling on this line stops both carriers immediately.

6.0 Requirements:

6.1 Solutions shall be maintained as specified on MP 309, pages 157 thru 161, 218 and 219.

6.2 The copper plate thickness in the holes will be 0.001 inch minumum unless otherwise specified in the planning.

6.3 Solder plate shall be 0.0003" minimum unless otherwise specified in the planning. A sample will be submitted to the Process Control Lab. for verification after the solder plate operation.

6.4 Thickness checks shall be performed at least once per 8 hour shift unless otherwise specified.

6.5 Each time that copper flash is performed on any multilayer boards one test pattern for every 8 hrs. of operation (containing 20 holes in a 4 hole x 5 hole pattern) shall be sent to the Process Control Lab. for cross sectioning and microscopic examination of the hole wall. There shall be no cracks in the hole wall nor evidence of irregular grain growth such as treeing.

6.6 Plating shall be smooth, fine grained, adherent, free from blisters, pits, scale, nodules and other defects which are detrimental to the utility, form, fit or function of the part.

6.7 When multilayer boards are being processed, one sample from each order must be sent to the Process Control Lab. to be cross sectioned to meet requirements of specified reference on planning.

6.8 During operation the plater must fill out the plating log book noting the type of boards being run and the amperage reading for copper and solder plate.

6.9 Process Engineering will maintain a log at the Plating station with plating amperages listed.

7.0 Shut Down Procedure

7.1 At the end of any run, shut down machine by depressing "AUTO STOP" push button on Master Control Panel. Machine can be shut down at any point in the automatic cycle, but the "LOAD" position is preferred.

7.2 Turn heat off on Stations 3, 9, and 10 by setting Partlow Controllers to 50°F. Leave heat on copper tanks at all times except if tanks are down for 48 hrs. or longer, in which case they should be turned off.

7.3 Turn off air agitation in each copper plating tank as soon as plating is completed for the day. Do not turn air back on until production parts are going to be plated at the beginning of the day.

7.4 The copper tanks must be dummy plated if the line has been down for 48 hours or more. To do this load 4 dummy panels (approximately 7" x 21.5" each) per flight bar for 8 successive loads to provide an automatic 54 minutes of plating prior to processing parts. Plate each load of panels at 150 amps. Allow panels to complete the plating process to obtain a solder test sample. Plate each load of panels in solder tank at 90 amps.

NOTE: Keep the filtering systems running at all times on the plating tanks.

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FIGURE #1
USED FOR ALL PROGRAMS EXCEPT COPPER FLASH

STEP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
LS 1																	X	X	X	X
LS 2	X		X		X		X		X		X		X		X					
LS 3		X		X		X		X		X		X		X		X				
LS 4	X	X							X	X										
LS 5			X	X							X	X								
LS 6					X	X							X	X						
LS 7							X	X							X	X				

X INDICATES CAM ACTIVATED

FIGURE #2
USED ONLY FOR COPPER FLASH

STEP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
LS 1		X		X		X		X		X		X		X		X	X	X	X	X
LS 2	X		X		X		X		X		X		X		X					
LS 3		X		X		X		X		X		X		X		X				
LS 4	X	X							X	X										
LS 5			X	X							X	X								
LS 6					X	X							X	X						
LS 7							X	X							X	X				

X INDICATES CAM ACTIVATED

ONLY 8 CAMS ARE CHANGED, ALL OF THEM ON LS 1

MANUFACTURING PROCEDURE

TITLE: PROCESS SOLUTION, MAKEUP AND CONTROL

MP 309

REV NO.	DESCRIPTION	MADE BY	DATE
5	Revised Para. 6.92.1.6	P.E. Hinton	1-15-74

1/23/74

1/25/74

6.92.1 Solution: Demineralized/Deionized Water

6.92.1.1 Location: Central Plant System. Tanks located underground, (outside) East Side Bldg. 801, A-7.

6.92.1.2 Tank Capacity: two tanks, 10,000 gal. each.

6.92.1.3 Source of Water: Deionizing System (H-57875).

6.92.1.4 Test Frequency: weekly for conductivity
monthly for solids

6.92.1.5 Process Control Limit:

Conductivity (Barnstead Meter) 3 ppm max. measured as NaCl
*Total Solids (Excluding Refractory) 10 ppm max.

6.92.1.6 Specification Limit:

Conductivity (Barnstead Meter) 10 ppm max. measured as NaCl
*Total Solids (Excluding Refractory) 16 ppm max.

*Refractory solids are collodial-sized particles of fused minerals such as silica. The refractory properties shall be tested by ignition of evaporative residues at 1100° to 1200°F (593° to 649°C).

MANUFACTURING PROCEDURE

PAGE 1 OF 2	
2. TITLE: PROCESS SOLUTION, MAKEUP AND CONTROL	3. MP 309/160A

5. REV. LTR	DESCRIPTION	7. MADE BY	8. DATE
F	Revised Paragraphs 6.157.1.3, 6.157.1.9, 6.157.10, 6.157.2.2	P.W. FECSIK	10-19-81

10. PRODUCT ENGINEERING	11. DATE 10/2/81	12.		13. DATE
14. PRODUCT	15. DATE 10/19/81	16.		17. DATE

18.

6.157.1 Solution: Tin-Lead (Solder) Plate Hi Thro

6.157.1.1 Location: Etched Circuitry Automatic Copper/Solder Plating Line, Stations #4 and #5 (T-203514). Column B-9

6.157.1.2 Tank Capacity: 350 gallons

6.157.1.3 Makeup: Boric Acid (MRO #5-0075) - 55 lbs.

Lead Fluoborate (51%) (MRO #5-1585) - 160 lbs.

Stannous Fluoborate (51%) (MRO #5-2410) - 400 lbs.

Fluoboric Acid (48%) (MRO #5-0095) - 90 gallons

Peptone Solution (Stabilized) (MRO #5-02501)-6 gallons

Water, Deionized - Balance

Anodes - 60/40 Solder (MRO #5-2602)

Operating Level: Five to seven inches from top of tank.

Dissolve 55 lbs. of boric acid in hot deionized water (30-40 gallons). Fill plating tank 1/3 full with deionized water and while stirring add the boric acid solution. Add Lead Fluoborate (160 lbs.) and stir. Add Fluoboric Acid (90 gals.) and stir. Add Stannous Fluoborate and stir. Add stabilized Peptone Solution and stir. Add anodes. Fill to six inches from top with deionized water and stir thoroughly.

NOTE: Protective clothing must be worn to protect skin and eyes from contact with makeup chemicals.

6.157.1.4 Analysis Frequency: Weekly

6.157.1.5 Process Control Limits:

1. pH 0.50 max. Do not test with glass electrodes.
2. Stannous Tin 24-32 gm/l
3. Lead 12-18 gm/l
4. Free Fluoboric Acid 180-320 gm/l
5. Percent of Tin in deposit 60-70%

NOTE: Boric Acid concentration in solution is to be maintained by hanging a porous inert anode bag containing boric acid in tank. Refill bag with boric acid as required.

6.157.1.6 Specification Limits:

1. pH no greater than 0.50	
2. Stannous Tin	22-34 gm/l
3. Lead	10-20 gm/l
4. Fluoboric Acid	160-350 gm/l
5. Percent of tin in deposit	50-70%

6.157.1.7 Operating Conditions:

Agitation - Mild (no air agitation). Use filter for agitation.

6.157.1.8 Renewal Frequency: Only by direction of Process Engineering.

6.157.1.9 Carbon Treatment:

1. Solution shall be carbon treated every (2) months.
2. Operator shall add five (5) gallons of Peptone to the bath when taken off carbon treatment.
3. A Hull Cell test will be performed and further additions shall be based on the results.
4. The Process Control Lab shall maintain a log and inform the Process area in the normal manner when the solution should be carbon treated.

6.157.1.10 Solution Additions:

The Process Control Lab shall add one (1) gallon of Peptone each Monday at the beginning of first shift, maintain a log of additions and notify the Process Area in the accepted manner when additions must be made.

6.157.2 Additional Tests:

6.157.2.1 Process Control Lab will run Hull Cell tests on Monday and Thursday at the beginning of first shift. Additions of Peptone will be based on the standard Hull Cell.

6.157.2.2 Percent Tin:

Solder plated panels will be provided to the Process Control Lab once each week for determination of % tin in solder plate.

MANUFACTURING PROCEDURE

1. TITLE: PROCESS SOLUTION, MAKEUP AND CONTROL	3. MP 309/219

5. REV LTR	DESCRIPTION	7. MADE BY	8. DATE
B	Revised Para.'s 6.216.1.5 and 6.216.1.6	C. Pignato	1-25-80

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
	6/18/80		
14. PRODUCT ASSURANCE	15. DATE	16.	17. DATE

18.

6.216.1 Solution: Acid Fluoboric, Pickle

6.216.1.1. Location: Etched Circuitry Automatic Copper/Solder Line, Station #6 T-203514

6.216.1.2 Tank Capacity: 110 Gallons

6.216.1.3 Makeup: Fluoboric Acid (48%) MRO #5-0095 — 22 Gallons

Water, Deionized — Balance

Operating Level - Five to seven inches from top of tank. Fill tank 1/2 full with deionized water. Very carefully add 22 gallons of Fluoboric Acid while stirring. Fill to six inches from top with deionized water. Stir thoroughly.

6.216.1.4 Analysis Frequency: Weekly

6.216.1.5 Process Control Limit: Fluoboric Acid - 130 to 180 gms/l

6.216.1.6 Specification Limit: 110 to 190 gms/l

6.216.1.7 Renewal Frequency:

Renew the solution every four weeks or sooner if requested by Process Engineering. The Process Control Lab shall maintain a log and inform the Process area in the normal manner when the solution must be removed.

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MANUFACTURING PROCEDURE

PAGE 1 OF 1			
2. TITLE: PROCESS SOLUTION, MAKEUP AND CONTROL			MP 309/158
5. REV. LTR.	DESCRIPTION	7. MADE BY	8. DATE
D	To Revise Para. 6.155.1.3	Richard C. Johnson R.C. Johnson	2/19/79
10. PROCESS ENGINEERING: Richard C. Johnson	11. DATE: 2/19/79	12.	13. DATE
QUALITY ASSURANCE	DATE: 3/12/79	16.	17. DATE

6.155.1 Solution: Acid Fluoboric, Pickle

6.155.1.1 Location: Etched Circuitry Automatic Copper/Solder Plating Line, Station #8 T-203514.

6.155.1.2 Tank Capacity: 110 Gallons

6.155.1.3 Makeup: Fluoboric Acid (48%) MRO #5-0095 11 Gallons
Water, Deionized Balance

Operating Level - Five to seven inches from top of tank.

Fill tank 1/2 full with deionized water. Very carefully add 11 gallons of Fluoboric Acid while stirring. Fill to six inches from top with deionized water. Stir thoroughly.

Note: Protective clothing must be worn to protect skin and eyes from contact with makeup chemicals.

6.155.1.4 Analysis Frequency: Weekly

6.155.1.5 Process Control Limit: Fluoboric Acid 45.0 to 75.0 gms/l.

6.155.1.6 Specification Limit: 35.0 to 85.0 gms/l.

6.155.1.7 Renewal Frequency:

Renew the solution every four weeks or sooner if requested by Process Engineering. The Process Control Lab. shall maintain a log and inform the Process area in the normal manner when the solution must be renewed.

MAC T-355 (REV.8-67)

MANUFACTURING PROCEDURE

1. SUBJECT	2. TITLE	3. MP
	PROCESS SOLUTION, MAKEUP AND CONTROL	MP 309/157

4. MFG. PRO. REV.	5 REV. LTR.	6. DESCRIPTION	7. MADE BY	8. DATE
	G	REVISE Para. 6.154.1.4	Richard C Johnson R.C. Johnson	2/15/79

9. SIGN OFF	10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
	Richard C Johnson	2/20/79		
	14. PRODUCT ASSURANCE	15. DATE	16.	17. DATE
	[illegible]	3/12/79		

18.

6.154.1 Solution: Alkaline Clean.

6.154.1.1 Location: Etched Circuitry Automatic Copper/Solder Plating Line, Station #9, T-203514

6.154.1.2 Tank Capacity: 110 Gallons

6.154.1.3 Makeup: Aldet 69 Lbs. (MRO #5-0668)
Tap Water Balance

Fill tank 1/2 full with deionized water. Add 69 lbs. of Aldet metal cleaner while stirring. Fill to 1 to 3 inches from top of tank with deionized water and stir thoroughly.

<u>NOTE:</u> Protective clothing must be worn to protect skin and eyes from contact with makeup chemicals.

6.154.1.4 Operating Temperature: ~~110°F ± 10°F~~ 135°F ± 10°F RCJ 11/10/81

6.154.1.5 Analysis Frequency: Weekly

6.154.1.6 Process Control Limit: Aldet 8-11 oz./gal.

6.154.1.7 Specification Limit: Aldet 7-12 oz./gal.

6.154.1.8 Renewal Frequency: Drain, clean tank, and renew monthly.

MAC T-398 (REV. 5-67)

MANUFACTURING PROCEDURE

2. TITLE	PROCESS SOLUTION, MAKEUP AND CONTROL	3.	MP 309/161
5. REV LTR	DESCRIPTION	7. MADE BY	8. DATE
E	CHANGE PARAGRAPH 6.158.1.3, 6.158.1.4	CR Dunham 7/13/81 C.R. DUNHAM	7-13-81
10. PROCESS ENGINEERING	11. DATE 7-14-81	12.	13. DATE
14. PRODUCT	15. DATE 7/27/81	16.	17. DATE

18.

6.168.1 Solution: Etch, Copper

6.158.1.1 Location: Etched Circuitry Automatic Copper/Solder Plating Line, Station #12 (T-203514). Column B-9

6.158.1.2 Working Capacity: 110 Gallons

6.158.1.3 Makeup: Metex PTH Etch G-2 (MRO #5-2373) 130 lbs.
Water, Deionized. Balance

Operating Level - Five to seven inches from top of tank.

Fill tank ½ full of deionized water. Add 130 lbs. of Metex PTH Etch G-2 while stirring. Fill to six inches from top with deionized water and stir thoroughly.

NOTE: Protective clothing must be worn to protect skin and eyes from contact with makeup chemicals.

1/25/82 DW

6.158.1.4 Analysis Frequency: ~~Once the first week following makeup and every two weeks thereafter.~~ NONE

~~6.158.1.5 Process Control Limit: 80-130% activity of Metex PTH Etch G-2.~~

~~6.158.1.6 Specification Limit: 70-150% activity of Metex PTH Etch G-2.~~

1/25/82 DW

6.158.1.7 Renewal Frequency: WEEKLY
Renew the solution ~~monthly or more frequently if requested by Process Engineering~~. The Process Control Lab shall maintain a log and inform the process area in the normal manner when the solution must be renewed.

1/25/82 DW

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MANUFACTURING PROCEDURE

PAGE	1 OF 1
1. TITLE	PROCESS SOLUTION, MAKEUP AND CONTROL
3.	MP 309/159

5. REV. LTR.	DESCRIPTION	7. MADE BY	8. DATE
D	REACTIVATION	Richard C Johnson R.C. Johnson	11/15/78

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
Richard C Johnson	11/15/78		
14. QUALITY ASSURANCE	15. DATE	16.	17. DATE
[signature]	11/15/78		

18.

6.156.1 Solution: Sulfuric Acid, Deoxidizer

6.156.1.1 Location: Etched Circuitry Automatic Copper/Solder Plating Line, Station #14, T-203514 (Col. B-9).

6.156.1.2 Tank Capacity: 110 Gal.

6.156.1.3 Makeup: Sulfuric Acid (MRO #5-0220) 13 gallons
Water Balance

Operating Level - Five to seven inches from top of tank.

Fill tank 1/2 full with deionized water. Carefully and slowly add 13 gallons of sulfuric acid while stirring solution. Fill to six inches from top with deionized water and stir thoroughly.

Caution: Addition of sulfuric acid to water generates considerable heat. Avoid splashing and too rapid addition.

Note: Protective clothing must be worn to protect skin and eyes from makeup chemicals.

6.156.1.4 Analysis Frequency: Weekly

6.156.1.5 Process Control Limits: Sulfuric Acid 140-220 gms/l.

6.156.1.6 Specification Limits: 120-240 gms/l.

6.156.1.7 Renewal Frequency:

Renew the solution every four weeks, or sooner if requested by Process Engineering. The Process Control Lab. shall maintain a log and inform the Process area in the normal manner when the solution must be renewed.

MANUFACTURING PROCEDURE

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1. TITLE: PROCESS SOLUTION, MAKEUP AND CONTROL	MP 309/218

5. REV LTR.	DESCRIPTION	7. MADE BY	8. DATE
C	REVISION OF PARAGRAPHS 6.215.1.3, 6.215.1.5, 6.215.1.6, 6.215.1.7, 6.215.1.8, and 6.215.1.9	C.R. Dunham / C.R. Dunham	6-16-81

10. PROCESS ENGINEERING	11. DATE	12.	13. DATE
	6-25-81		
14. PRODUCT ASSURANCE	15. DATE	16.	17. DATE
	7/29/81		

6.215.1 Solution: Copper Plate, Acid

6.215.1.1 Location: Etched Circuitry Automatic Copper/Solder Plating Line, Stations 16-17; 18-19; 21-22 and 23-24 (Column B-9).

6.215.1.2 Working Capacity: 4 Tanks, 350 Gal. each

Operating Level - Five to seven inches from top of tank.

Operating Temperature - 70-90°F.

6.215.1.3 Makeup of each tank:

Lea-Ronal Copper Sulfate Solution
(MRO #5-2376) 107 Gal.

Sulfuric Acid
(MRO #5-0210) 549 Lbs.

Lea-Ronal Copper Gleam PCM
(MRO #5-0251) 1.75 Gal.

Hydrochloric Acid
(MRO #5-0101) 300 ml

Half fill the tank with deionized water. Add in order while tank is being air agitated: 107 gallons of copper sulfate solution and slowly with caution 549 lbs. of sulfuric acid. The rate of addition of the sulfuric acid should be such that the solution temperature does not exceed 120°F. When all of the sulfuric acid has been added, allow temperature to cool to 90°F. Subsequently add 300 ml of hydrochloric acid and 1.75 gallons of copper gleam PCM. Hang copper anodes in tank. Add deionized water to six inches below top of tank. After ½ hour minimum agitation, submit sample to Process Control Laboratory for analysis. Dummy the solution for 4 hours at 25 ASF before startup.

NOTE: Addition of sulfuric acid is accompanied by considerable evolution of heat. Avoid splashing; Partlow temperature controllers will not tolerate a temperature in excess of 120°F. Wear goggles and protective clothing during makeup.

6.215.1.4 Periodic Additions:

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The Copper Gleam PCM must be replenished during operation. During normal continuous operation add ~~750~~ mls to each tank every ~~4~~ hours. Alternately add 300 mls per every 1,000 amp-hours of operation.

6.215.1.5 Analysis Frequency:

1) Copper sulfate and sulfuric acid once per week when in use.
2) Chloride every Monday and Thursday.
3) Copper Gleam PCM weekly when in use using Hull Cell.

6.215.1.6 Process Control Limits:

1) Cu., 2.60 - 3.30 oz/gal
2) Sulfuric Acid (H_2SO_4), 23 - 27 oz/gal.
3) Chloride, 80-95 ppm
4) Copper Gleam PCM, as determined by Hull Cell test

6.215.1.7 Specification Limits:

1) Cu., 2.30 - 3.60 oz/gal.
2) Sulfuric Acid (H_2SO_4), 22-28 oz/gal.
3) Chloride, 75-105 ppm
4) Copper Gleam PCM, as determined by Hull Cell test.

6.215.1.8 Filtration and Carbon Treatment:

Solution shall be filtered continuously. Solution shall be carbon treated on request by Process Engineering. The filter elements (MRO #52-0790) shall be replaced every month. Before replacing the filter elements, soak the elements 2-3 hours in hot water to remove sizing.

6.215.1.9 The lab will run a Hull Cell test on the copper bath as requested by the Process Engineer or if the bath is down for a 48 hour period or longer.